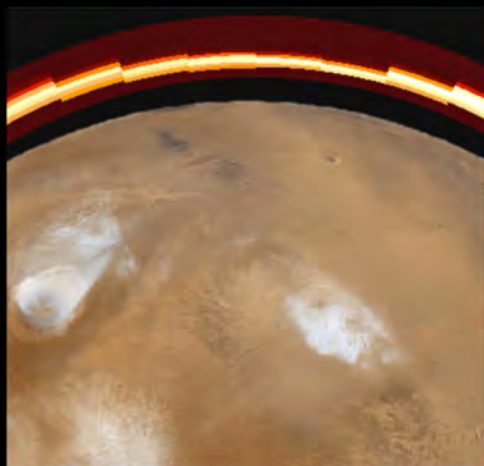
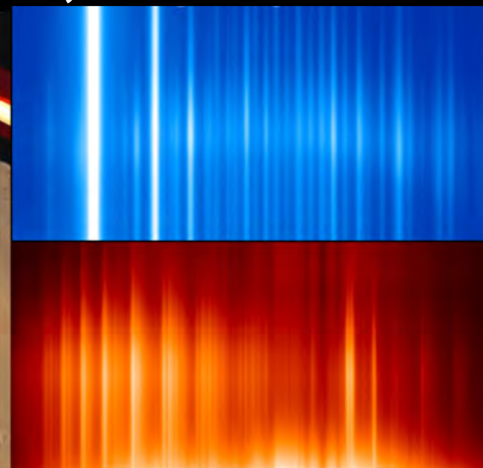
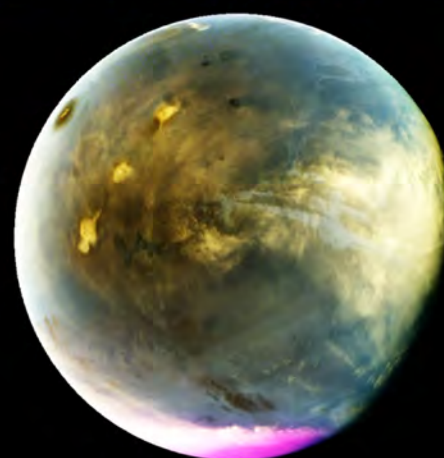
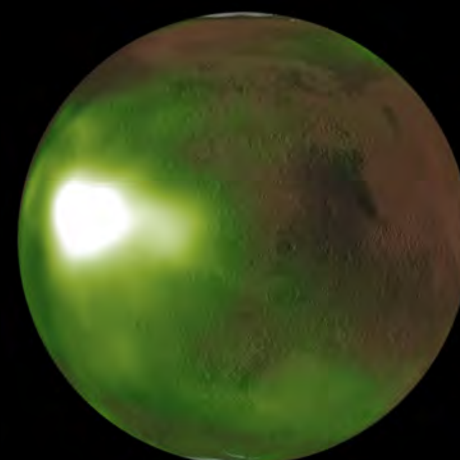
Surprises from MAVEN at Mars:

Meteor showers, aurora, and a new water loss paradigm

Arizona State University – School of Earth and Space Exploration

23 September, 2020

Nick Schneider and the MAVEN Imaging UV Spectrograph Team

Laboratory for Atmospheric & Space Physics, U. Colorado

Surprises from MAVEN at Mars

- Mars, MAVEN & IUVS: a quick overview
- Selected highlights
  - Comet Siding Spring's encounter with Mars
  - Three types of aurora on Mars
  - A new paradigm for Mars water loss
- MAVEN: what's ahead?

- Unifying themes
  - ➢ Interconnectedness of all branches of planetary science
  - ➢ Planetary responses to internal & external forcings

The MAVEN IUVS Science Team

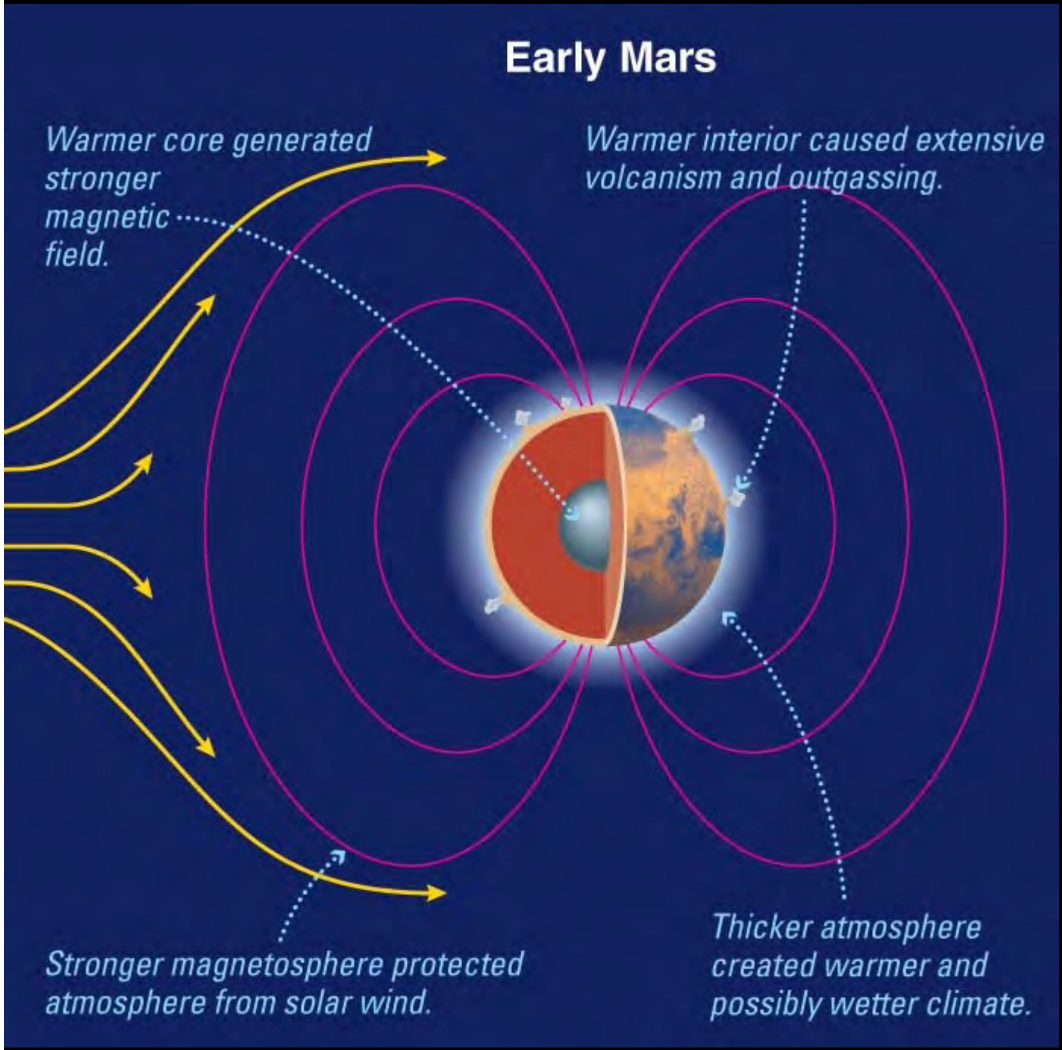
- Nick Schneider, lead
- Bill McClintock, instrument scientist
- Justin Deighan, deputy lead for operations
- Sonal Jain, deputy lead for data products & analysis

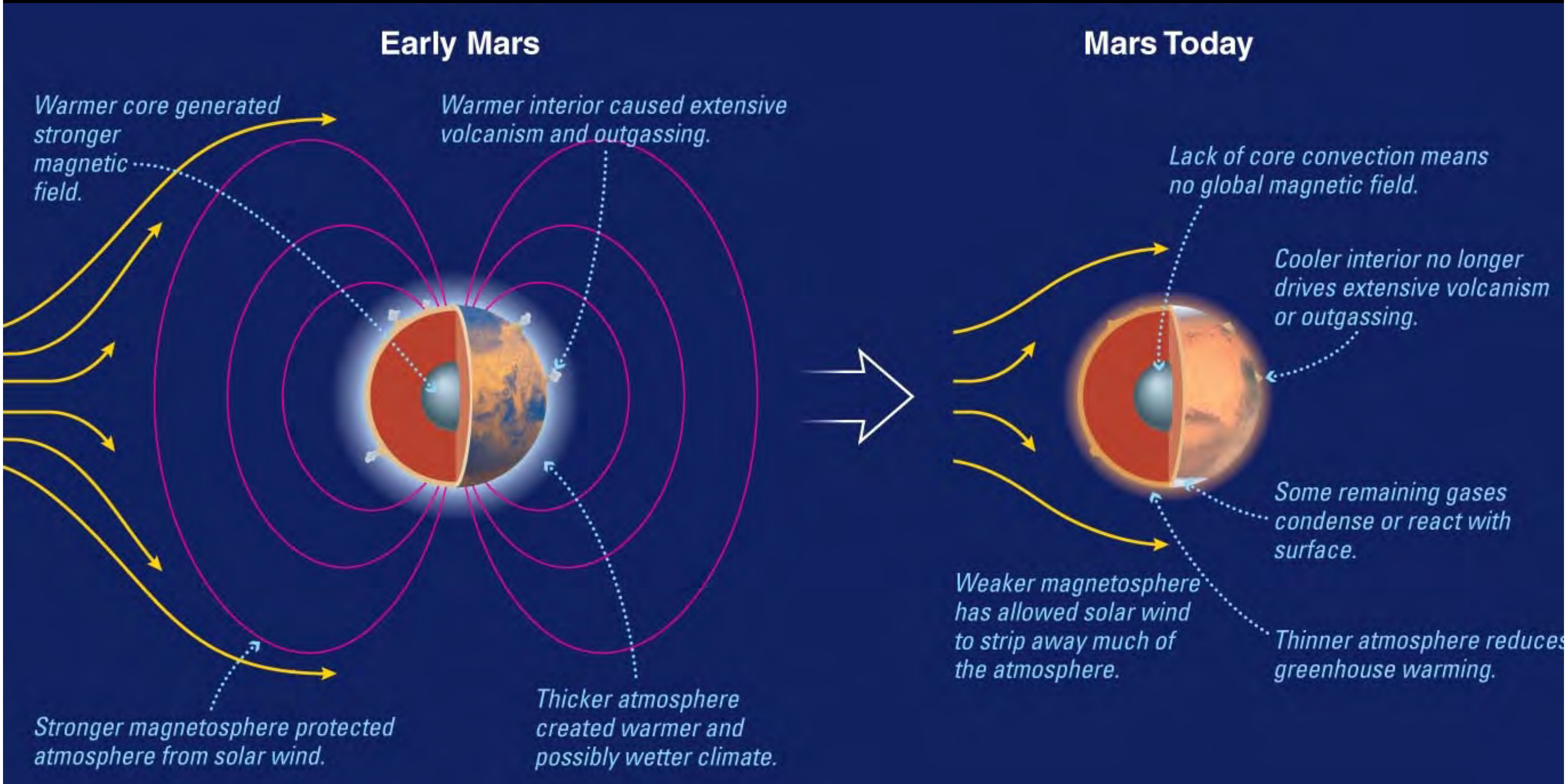
- LASP: Ian Stewart, Mike Chaffin, Matteo Crismani, Kyle Connour, Eryn Cangi, Greg Holsclaw, Dale Thieling, Chris Jeppesen, Ryan Held, Randy Meissner, Josh Elliott, with past & present undergrads Katie Fiztgerald, Josh Lothringer, Jeremey Emmet, Natalie Bremer, Sam Stuver, Cami Nasr, Zac Milby, Alysa Derks, Hannah Hartung, Allyson Leffler, Jenna Lowe, Ben Johnston
- LATMOS (Paris): Franck Montmessin, Franck Lefevre, Jean-Yves Chaufray
- Boston U.: John Clarke, Majd Mayyasi, Dolon Bhattacharya
- U. Arizona: Roger Yelle, Fayu Jiang, Daniel Lo
- Naval Research Lab: Mike Stevens
- Computational Physics Inc.: Scott Evans, John Corriera

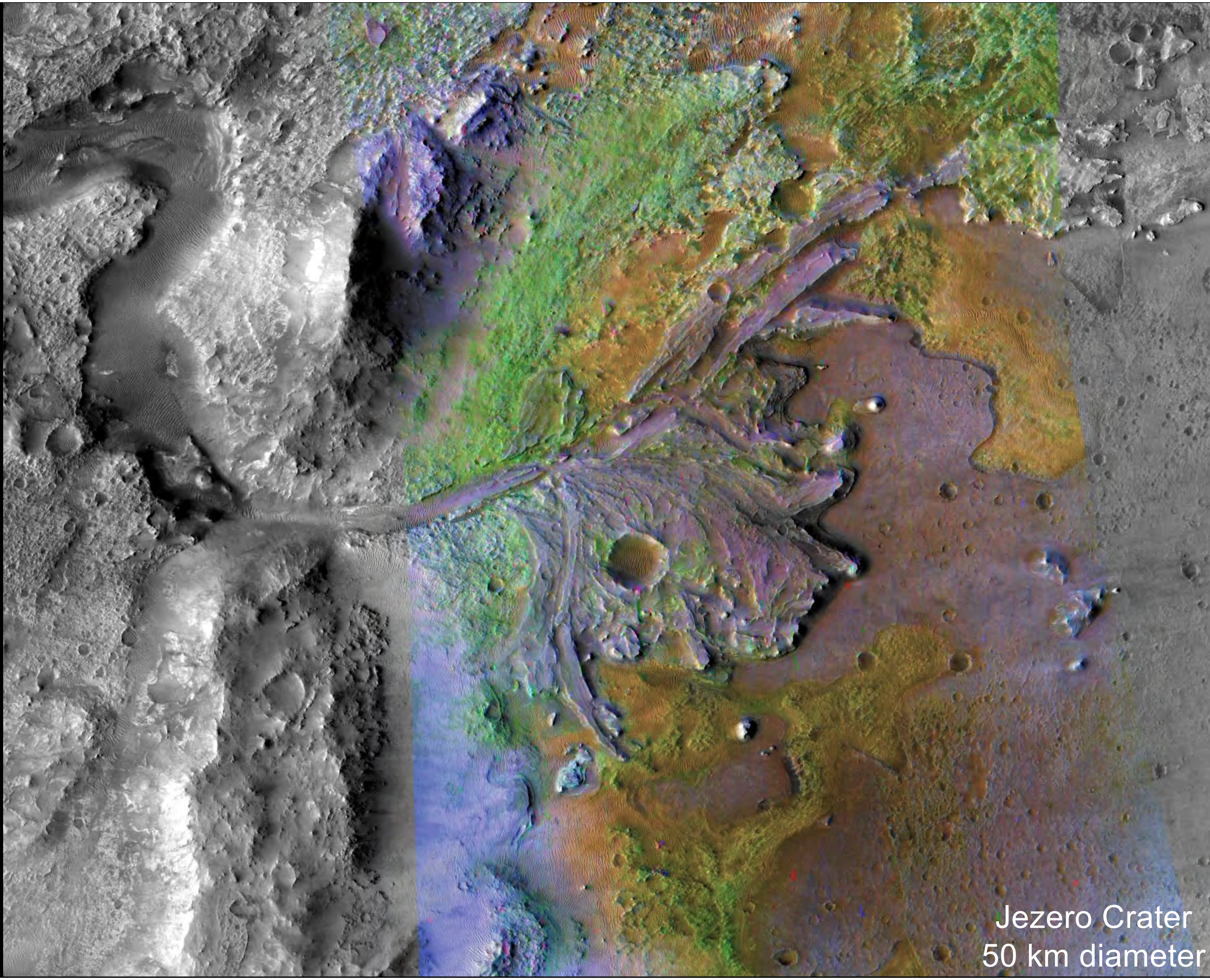
Mars’ size and distance from the Sun caused planetary evolution to make Mars less habitable

12,756 km Diameter

6,794 km Diameter


Early Mars
Warmer core generated stronger magnetic field.
Warmer interior caused extensive volcanism and outgassing.
Stronger magnetosphere protected atmosphere from solar wind.
Thicker atmosphere created warmer and possibly wetter climate.


Early Mars
Mars Today
Warmer core generated stronger magnetic field.
Warmer interior caused extensive volcanism and outgassing.
Stronger magnetosphere protected atmosphere from solar wind.
Thicker atmosphere created warmer and possibly wetter climate.
Lack of core convection means no global magnetic field.
Cooler interior no longer drives extensive volcanism or outgassing.
Some remaining gases condense or react with surface.
Weaker magnetosphere has allowed solar wind to strip away much of the atmosphere.
Thinner atmosphere reduces greenhouse warming.


Jezero Crater
50 km diameter

If Mars had a thick atmosphere, where it is now?
If Mars had an ocean, where is all the water now?

- Frozen at the poles?
  - Not enough!
- Locked underground?
  - Not *nearly* enough!

What other possibilities are left?

- Escaped to space?
  - *Maybe…*

MAVEN's Big Questions

The MAVEN mission is investigating three primary science questions:

1. What is the current state of the upper atmosphere and what processes control it?

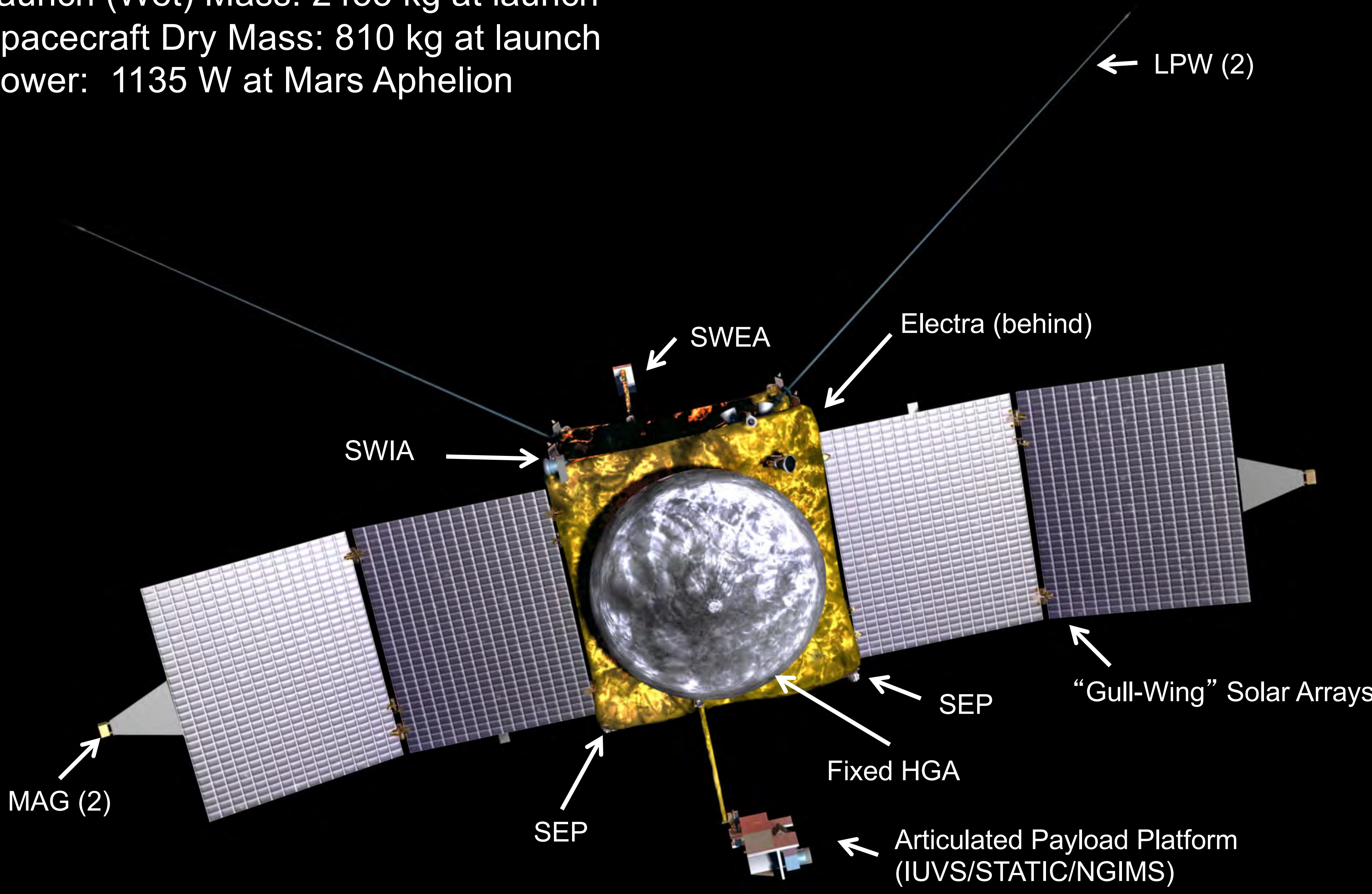
2. What is the escape rate at the present epoch and how does it relate to the controlling processes?

3. What has the total loss to space been through time?

- … and can the measured loss explain the major changes in Mars atmosphere and climate?

The MAVEN Spacecraft

- Launch (Wet) Mass: 2455 kg at launch
- Spacecraft Dry Mass: 810 kg at launch
- Power: 1135 W at Mars Aphelion



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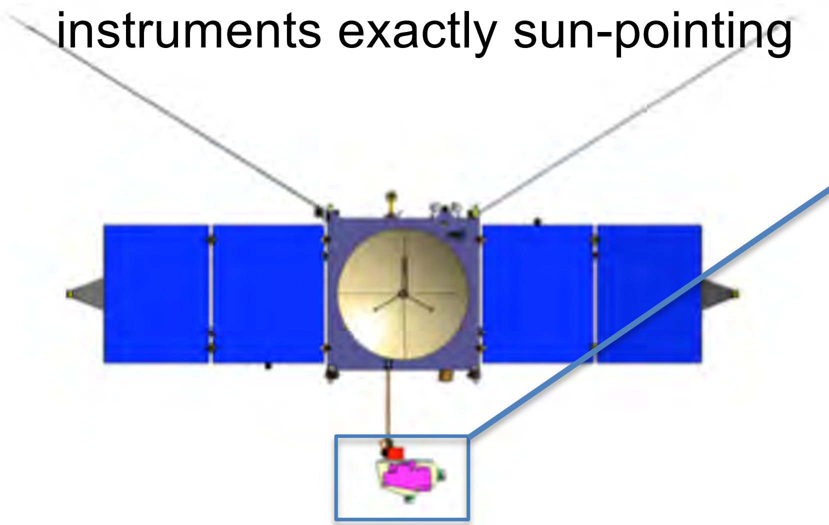
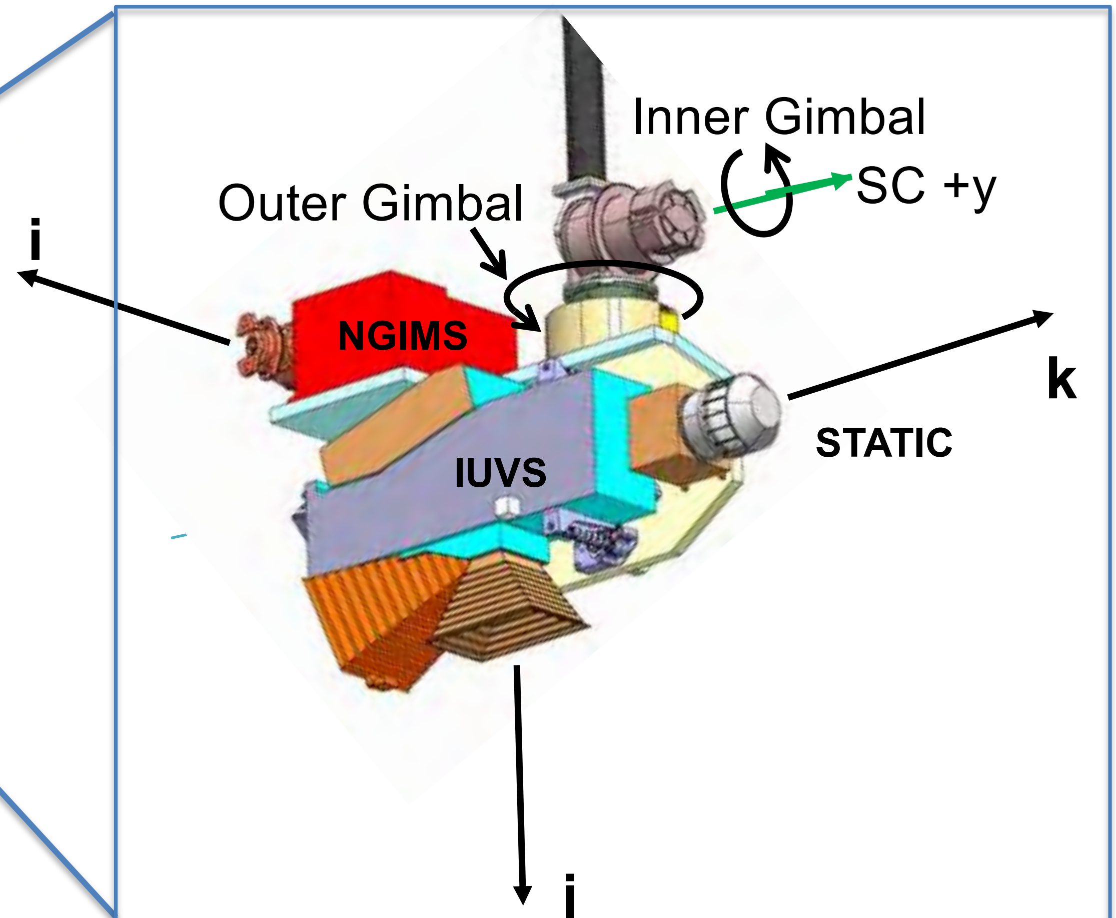
IUVS Accommodation & Pointing Capability

During most normal operations, the spacecraft flies with solar arrays and body-mounted instruments exactly sun-pointing

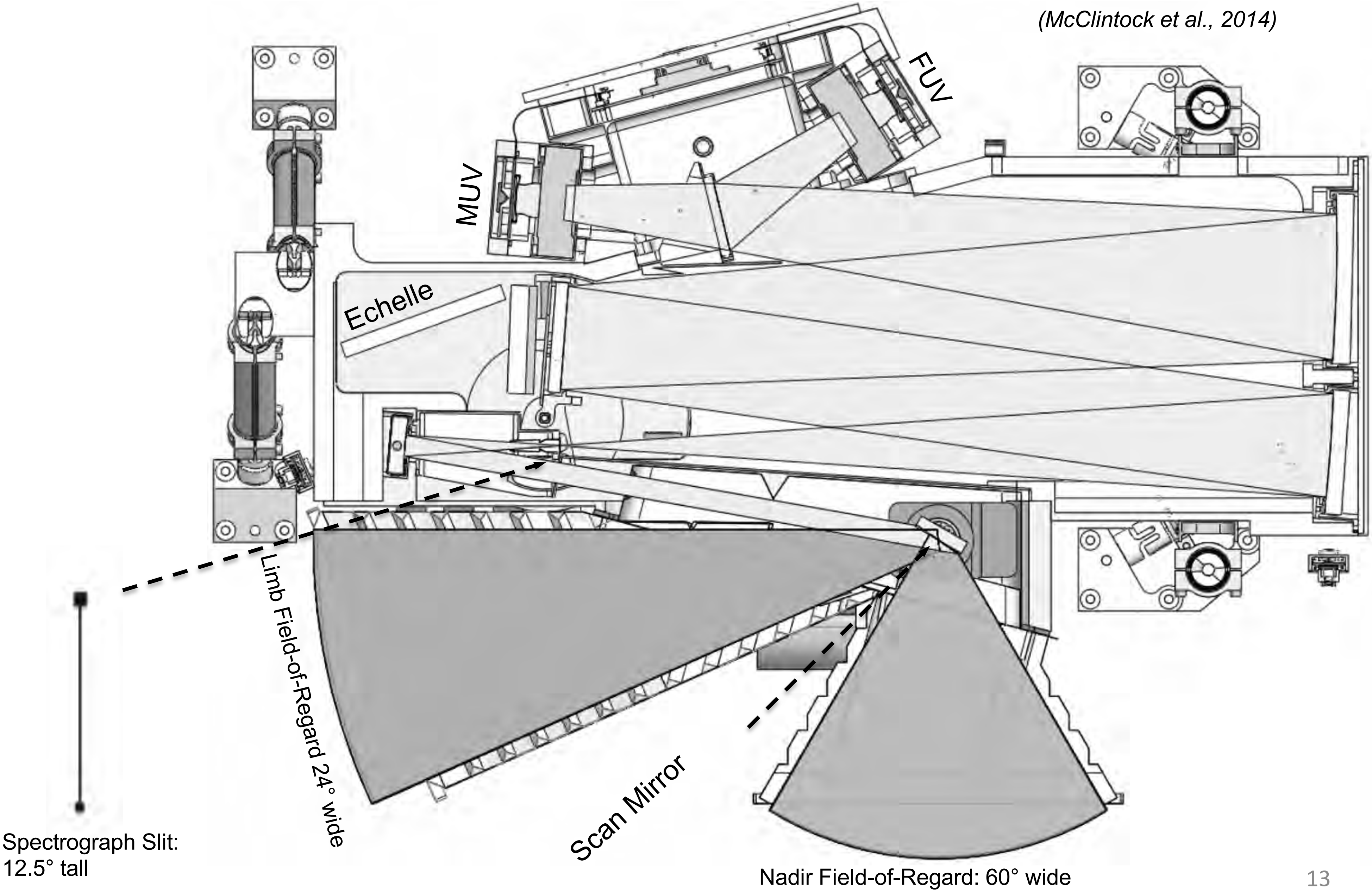
IUVS, NGIMS and STATIC are located on the Articulated Payload Platform (APP) which uses uses two gimbals to orient one instrument axis





2-axis gimbals allow IUVS to observe at >50% duty cycle, obtaining limb scans, coronal scans and disk maps

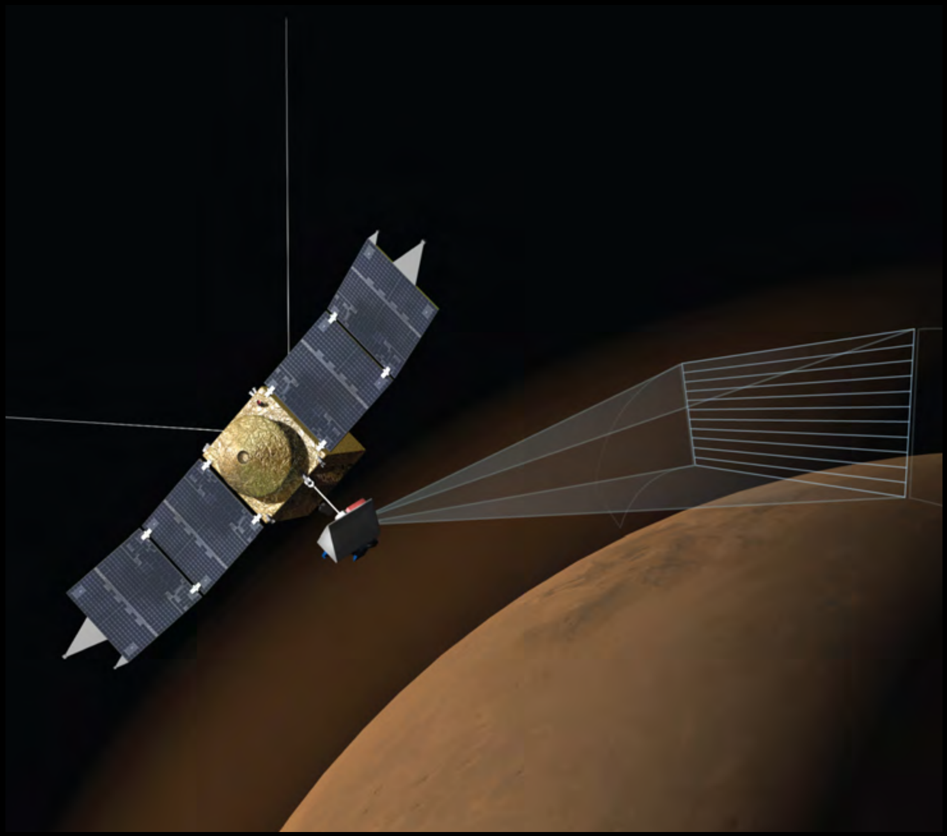
IUVS Optical Layout

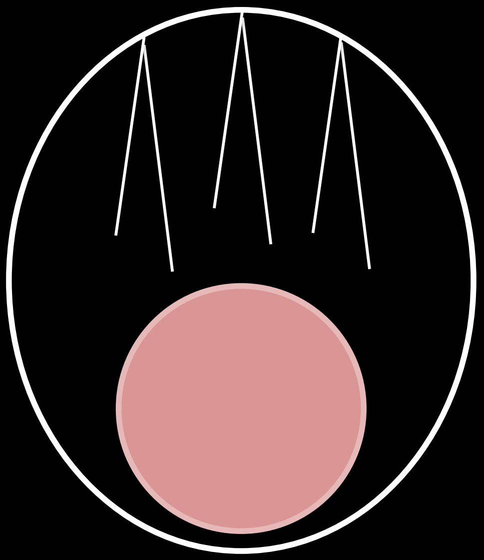


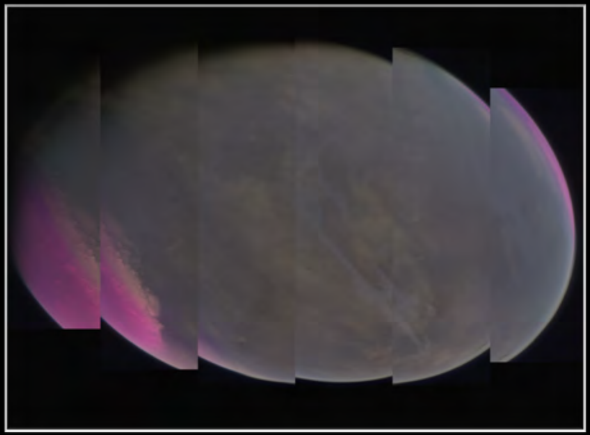

REMOVE BEFORE FLIGHT
REMOVE BEFORE FLIGHT
REMOVE BEFORE FLIGHT

IUVS Unique Characteristics

- Imaging spectroscopy via gimbals & scan mirror
- Multiple observing modes at >50% duty cycle
- 3 channels optimized for different science
- Unique orbit spans 150km to ~2 R_M altitude
- Full suite of particles & fields instruments
- Addresses issues across planetary science



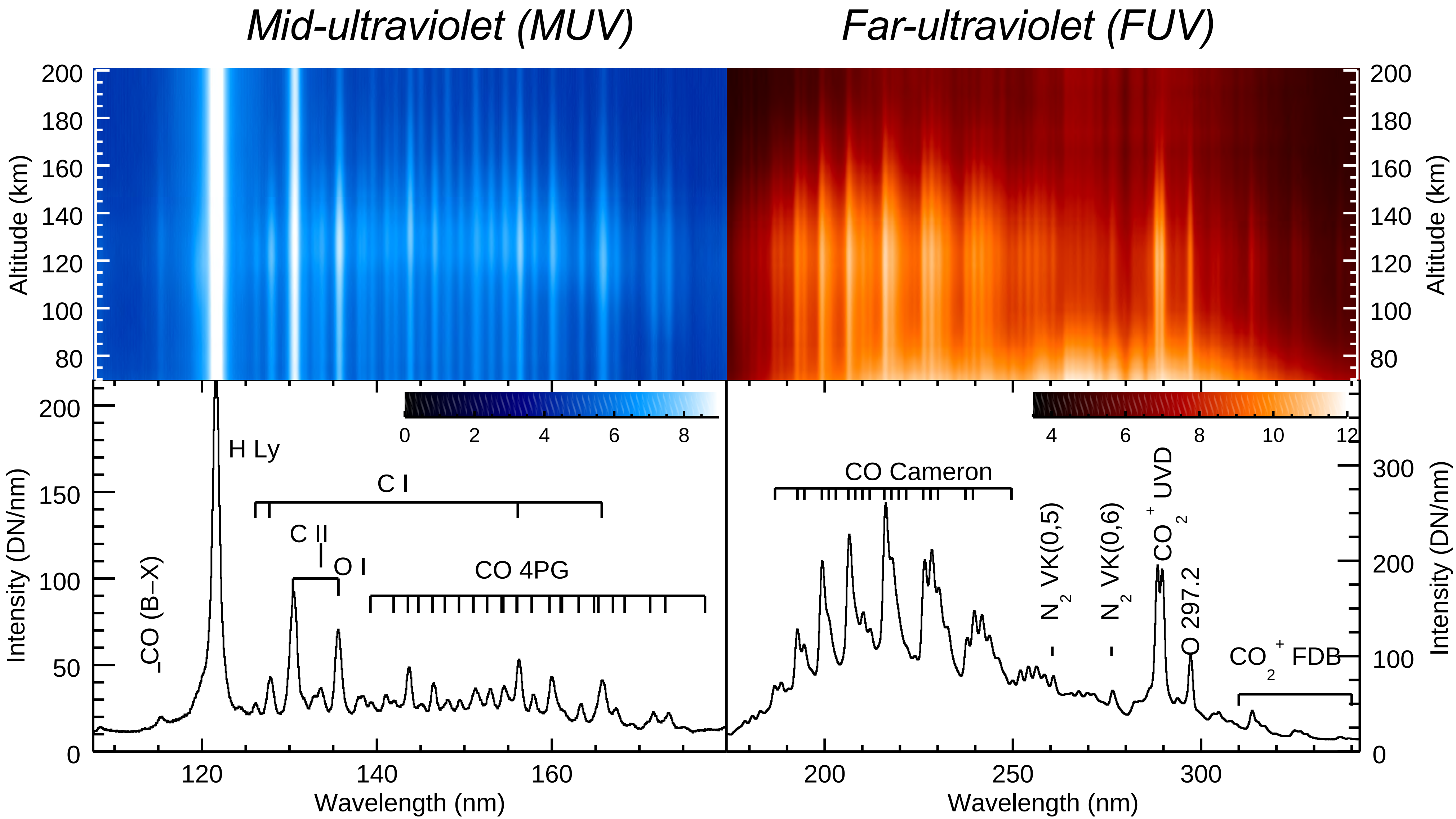




We use limb scans to map the chemical makeup and vertical structure across Mars' upper atmosphere

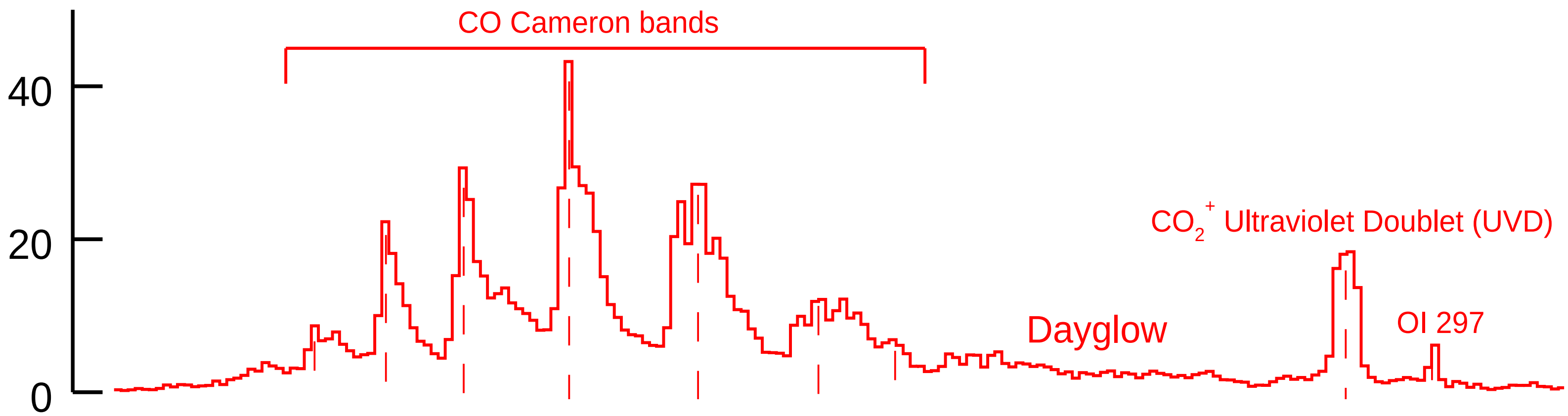
We also observe near apoapsis, making spectral images of the planet in many swaths.

Mars UV Spectrum - *not a model!*



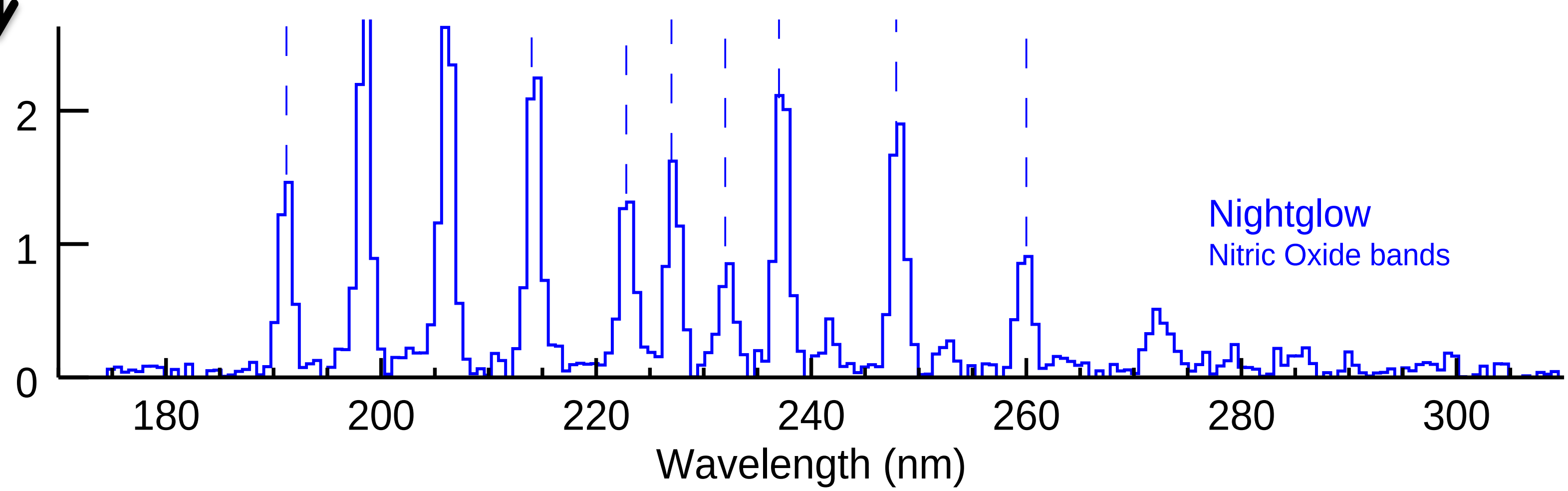
- Nearly 60 hours total integration
- Most emissions from CO_2 dissociation & ionization products (Barth et al. 71)

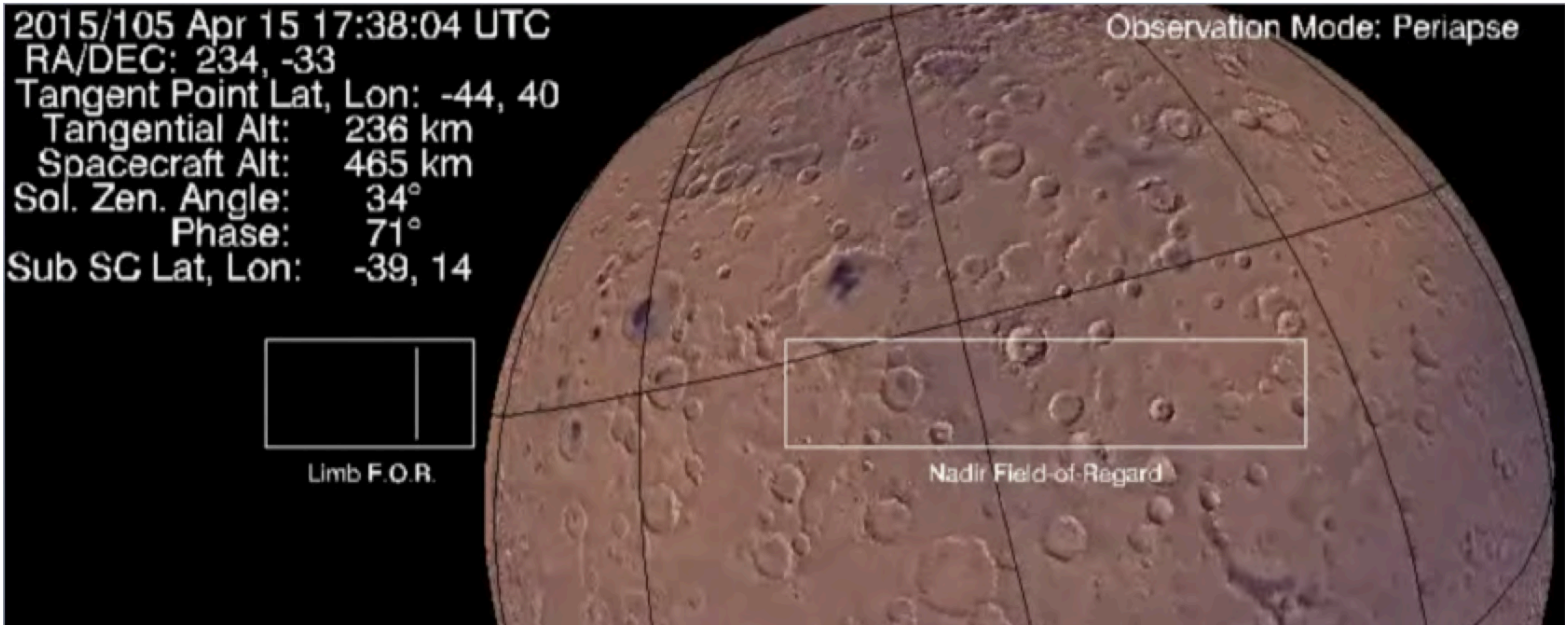
Typical IUVS Spectra, Day & Night



↑ *Dayglow* emissions caused by EUV photons & photo-electrons; can learn about composition & energy deposition

↓ *Nightglow* emissions caused by N + O recombination near winter pole; can learn about atmospheric circulation





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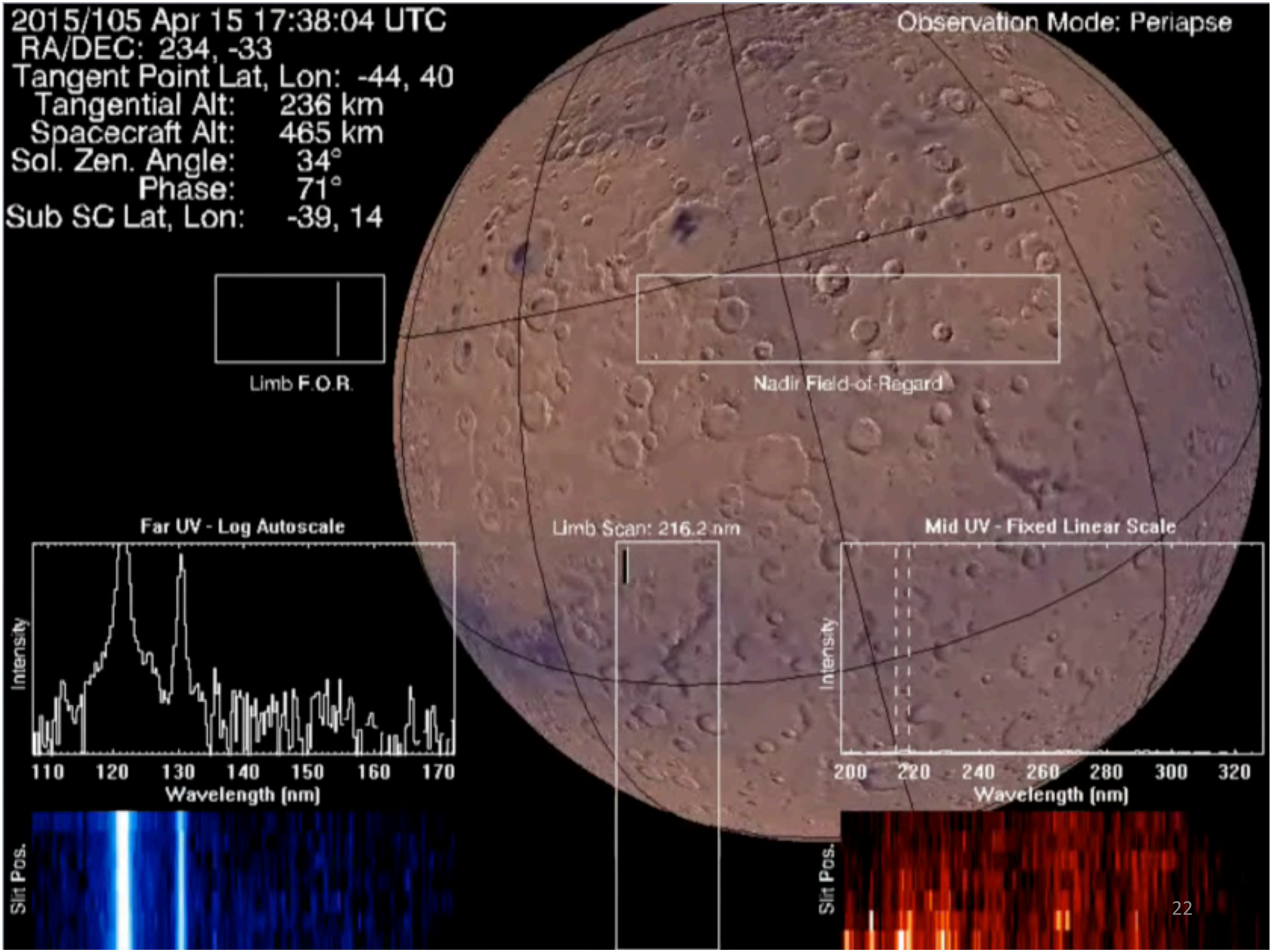
Tangent Point Lat, Lon: -44, 40
Tangential Alt: 236 km
Spacecraft Alt: 465 km
Sol. Zen. Angle: 34°
Phase: 71°
Sub SC Lat, Lon: -39, 14
Observation Mode: Periapse
Limb F.O.R.
Nadir Field-of-Regard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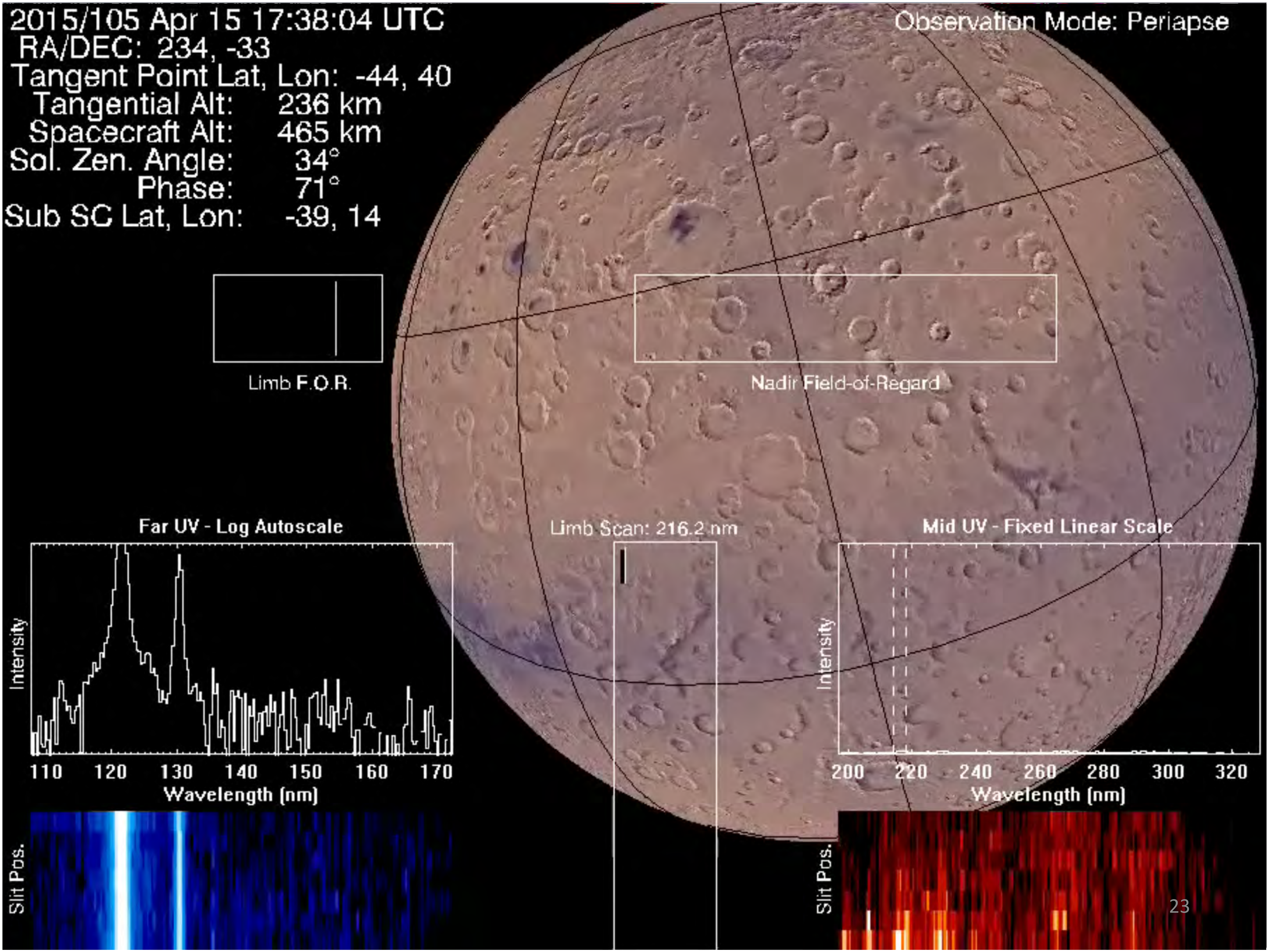
Limb F.O.R.
Nadir Field-of-Regard
Far UV - Log Autoscale
Intensity
110 120 130 140 150 160 170
Wavelength (nm)
Slit Pos.
Limb Scan: 216.2 nm
Mid UV - Fixed Linear Scale
Intensity
200 220 240 260 280 300 320
Wavelength (nm)
Slit Pos.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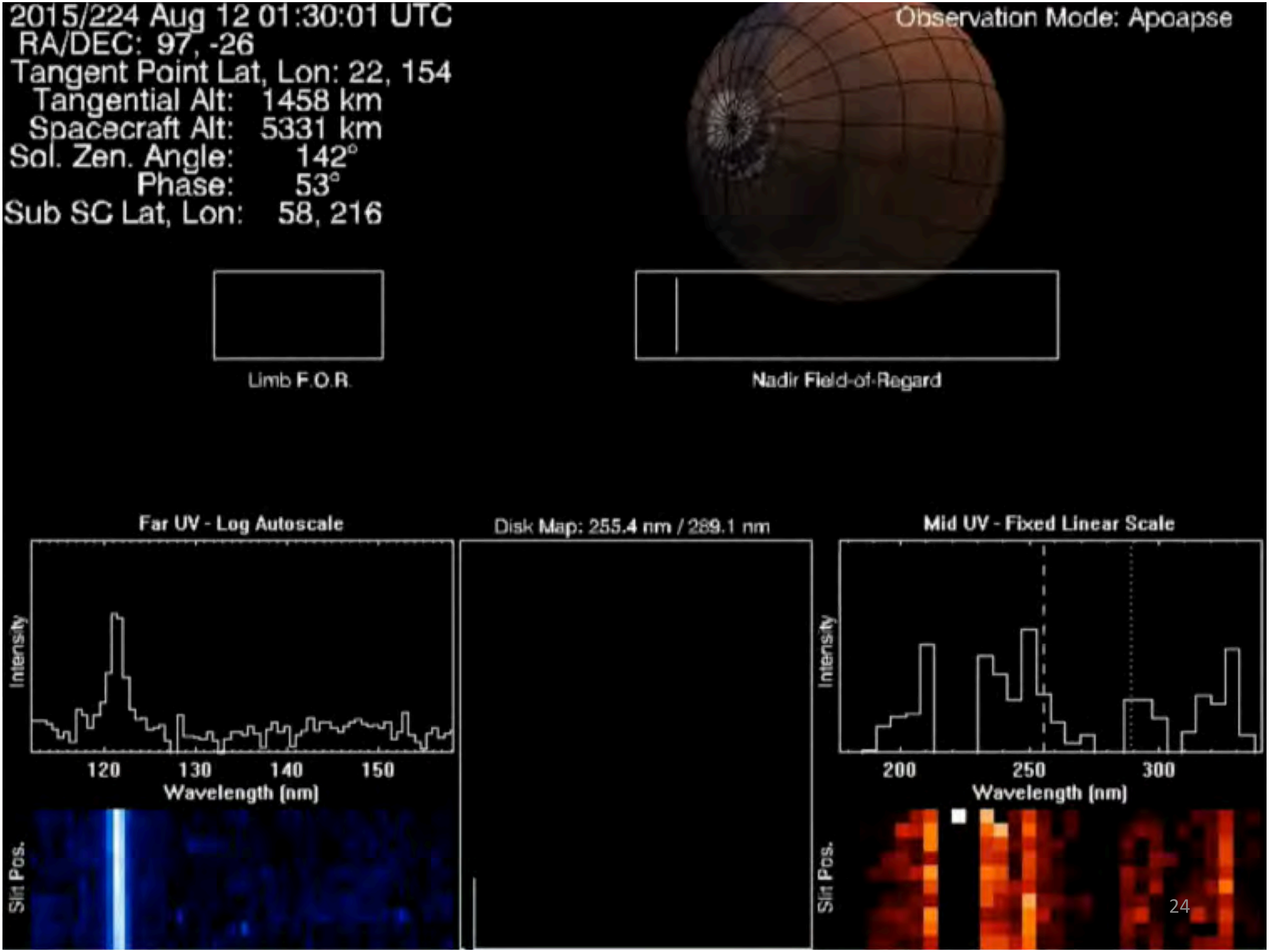
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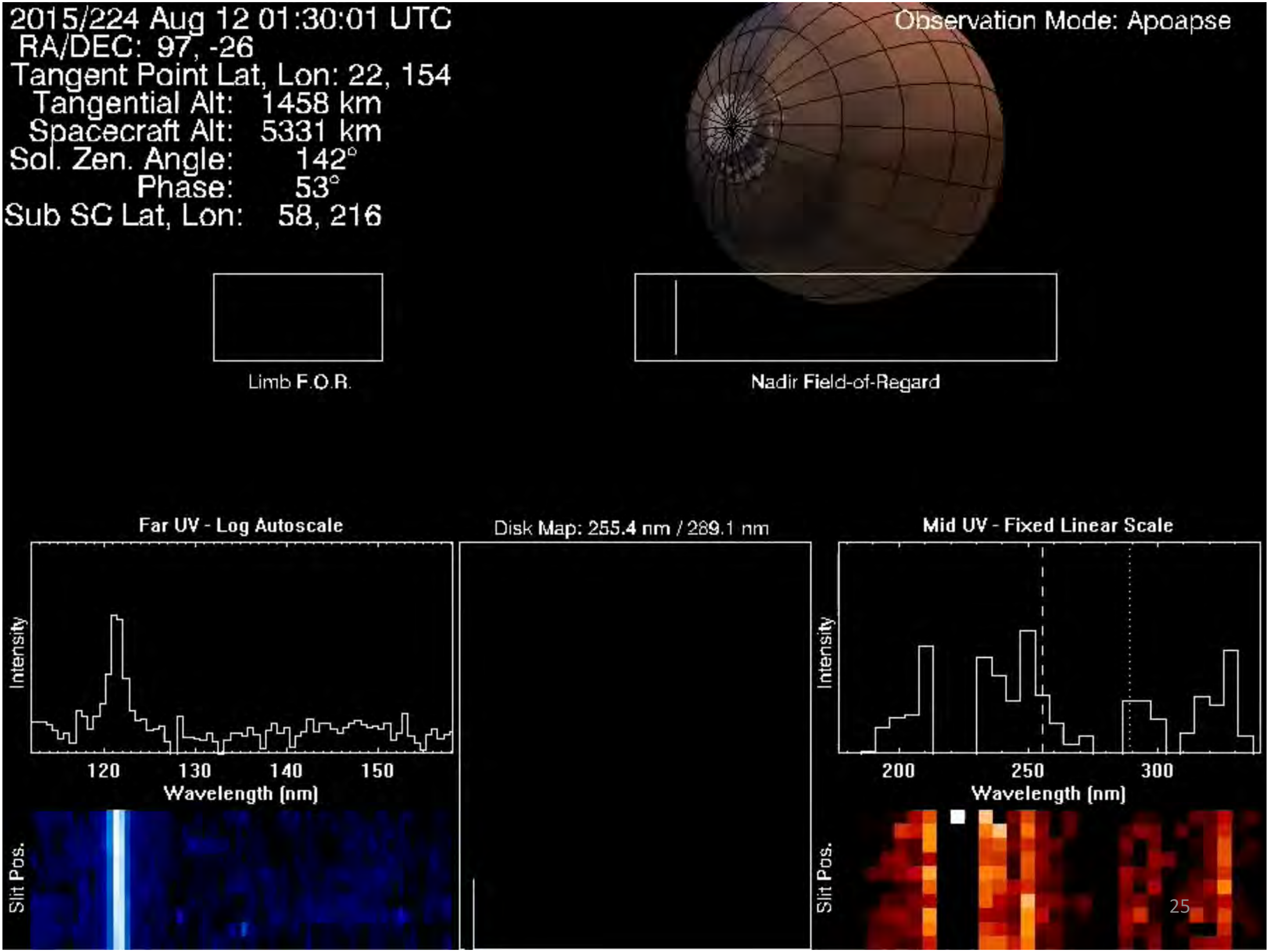
RA/DEC: 97, -26
Tangent Point Lat, Lon: 22, 154
Tangential Alt: 1458 km
Spacecraft Alt: 5331 km
Sol. Zen. Angle: 142°
Phase: 53°
Sub SC Lat, Lon: 58, 216
Observation Mode: Apoapse
Limb F.O.R.
Nadir Field-of-Regard
Far UV - Log Autoscale
Intensity
120
130
140
150
Wavelength (nm)
Slit Pos.
Disk Map: 255.4 nm / 289.1 nm
Mid UV - Fixed Linear Scale
Intensity
200
250
300
Wavelength (nm)
Slit Pos.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300
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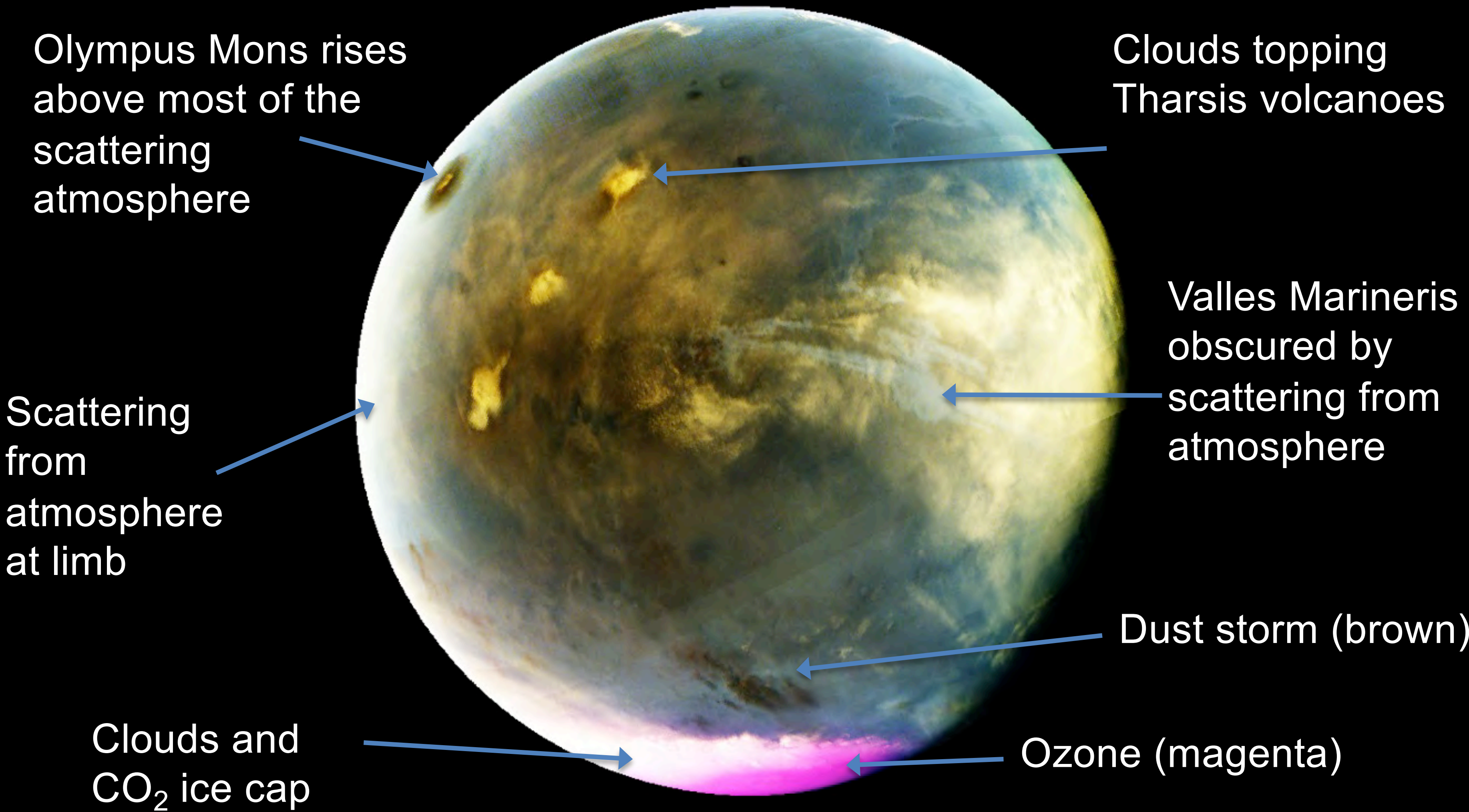
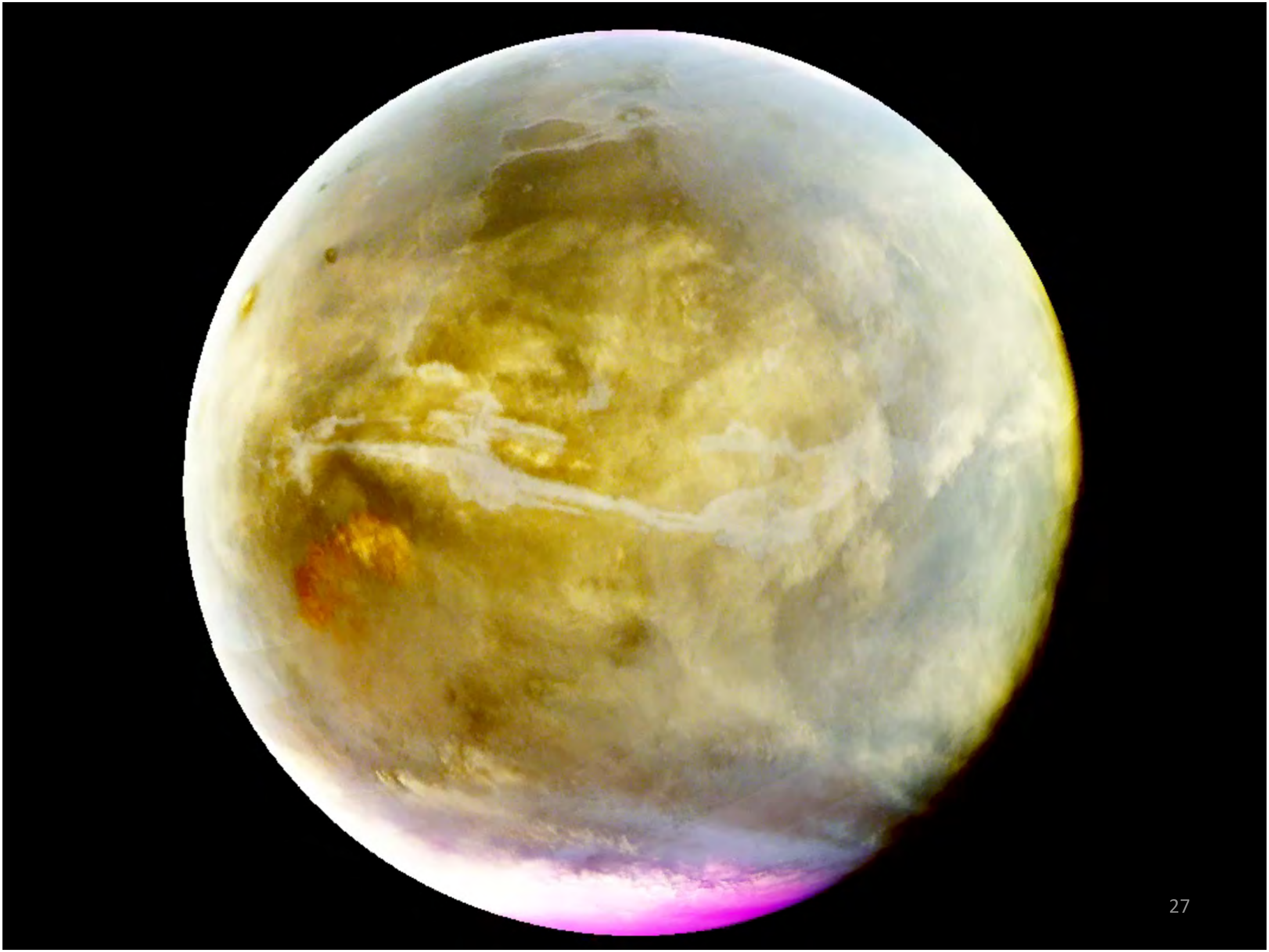
Slit Pos.

Mars Clouds as seen by MAVEN/IUVS



With Justin Deighan, Mike Wolff, Alyssa Derks




NASA
NASA SAYS IT HAS
NO EXPLANATION
FOR THE CLOUDS' ORIGINS
The Weather Channel

Surprises from MAVEN at Mars

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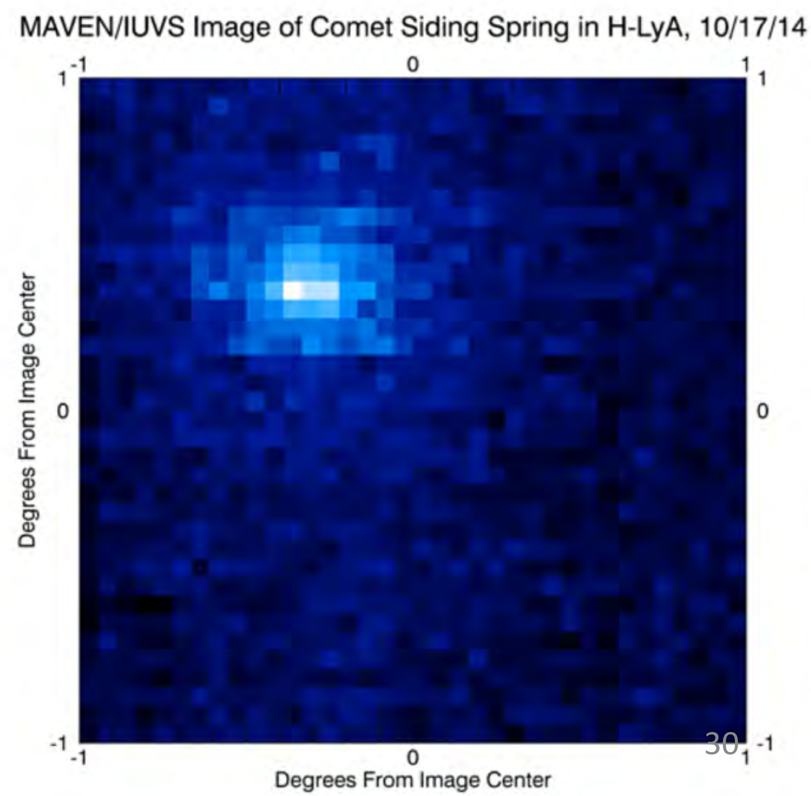
Mars (& MAVEN's) Close Encounter With Comet Siding Spring

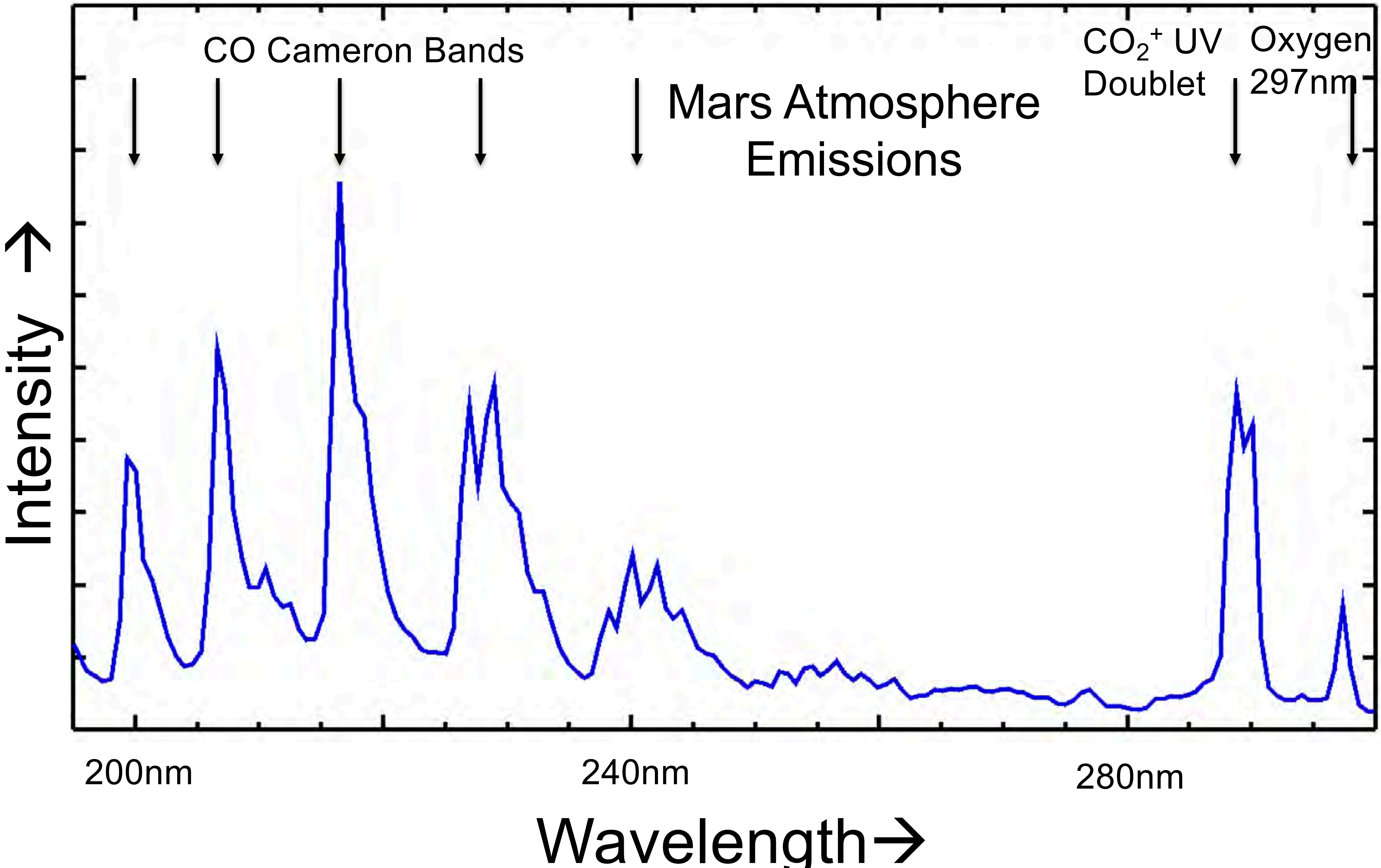
Breckland Skies Observatory

- Comet Siding Spring (CSS) had a close approach (~140,000 km) to Mars on 19 Oct. 2014
- Spacecraft and instruments took protective measures to ensure safety
- Strong desire to observe comet and its effects on Mars' atmosphere

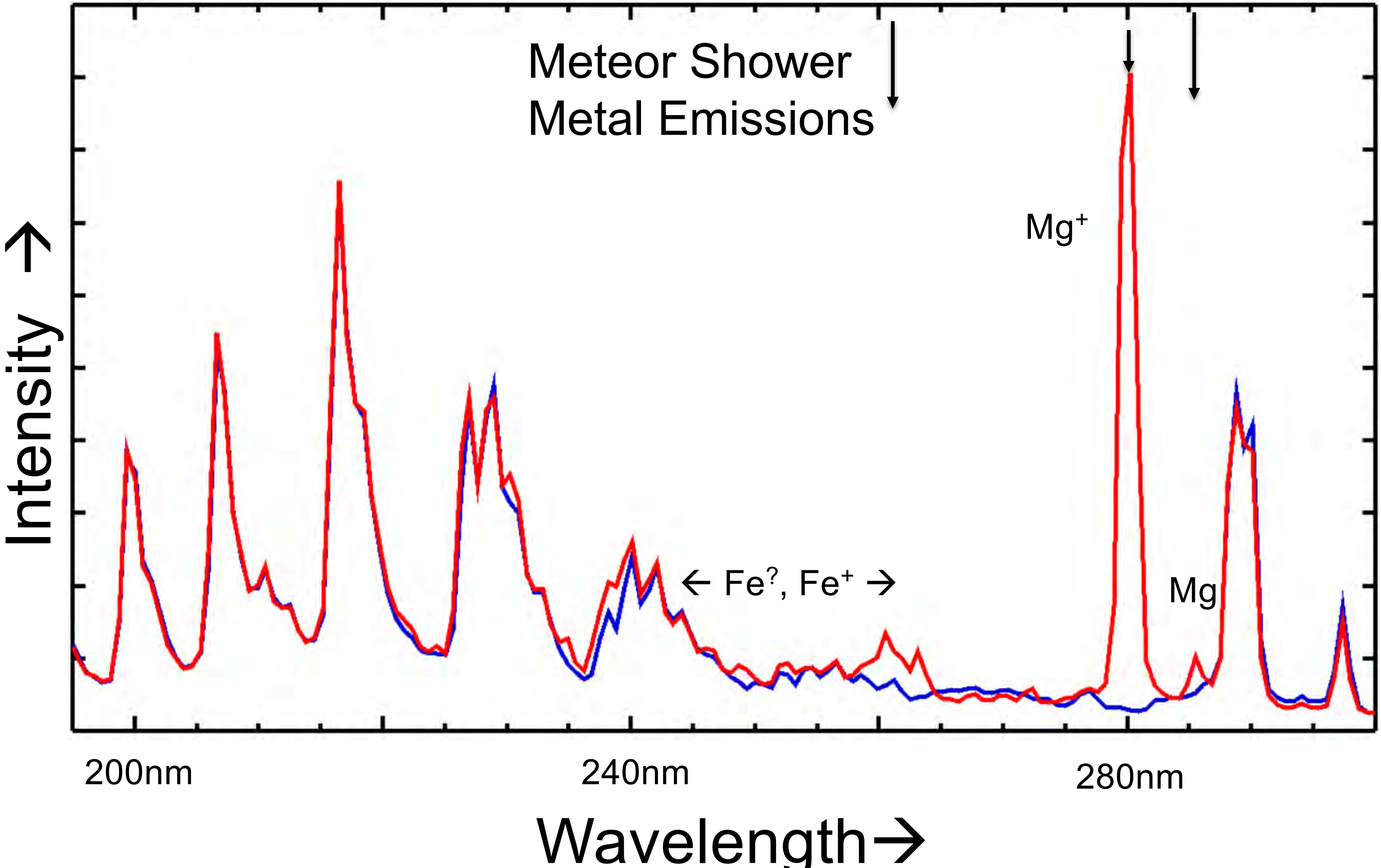


- MAVEN IUVS imaged CSS in scattered solar Lyman-alpha two days before closest approach to Mars
- H detected to distance of ~150,000 km (comparable to Mars miss distance of comet)
- Suggested significant potential risk to spacecraft

MAVEN/IUVS Spectrum of Mars Atmosphere Before Comet Siding Spring



MAVEN/IUVS Spectrum of Mars Atmosphere ~6 hours after Comet Siding Spring Closest Approach



Conclusions: Mars' Intense Meteor Shower

- Brightest emissions imply densities of ~10^4 Mg^+/cm^3
- Emission detected globally over the following day with significant spatial/temporal structures
- Hemispheric integration of initial Mg^+ densities yields 3,000-16,000 kg of cometary dust deposited
- Total dust mass implies zenithal hourly rates of visible meteors of thousands to tens of thousands per hour

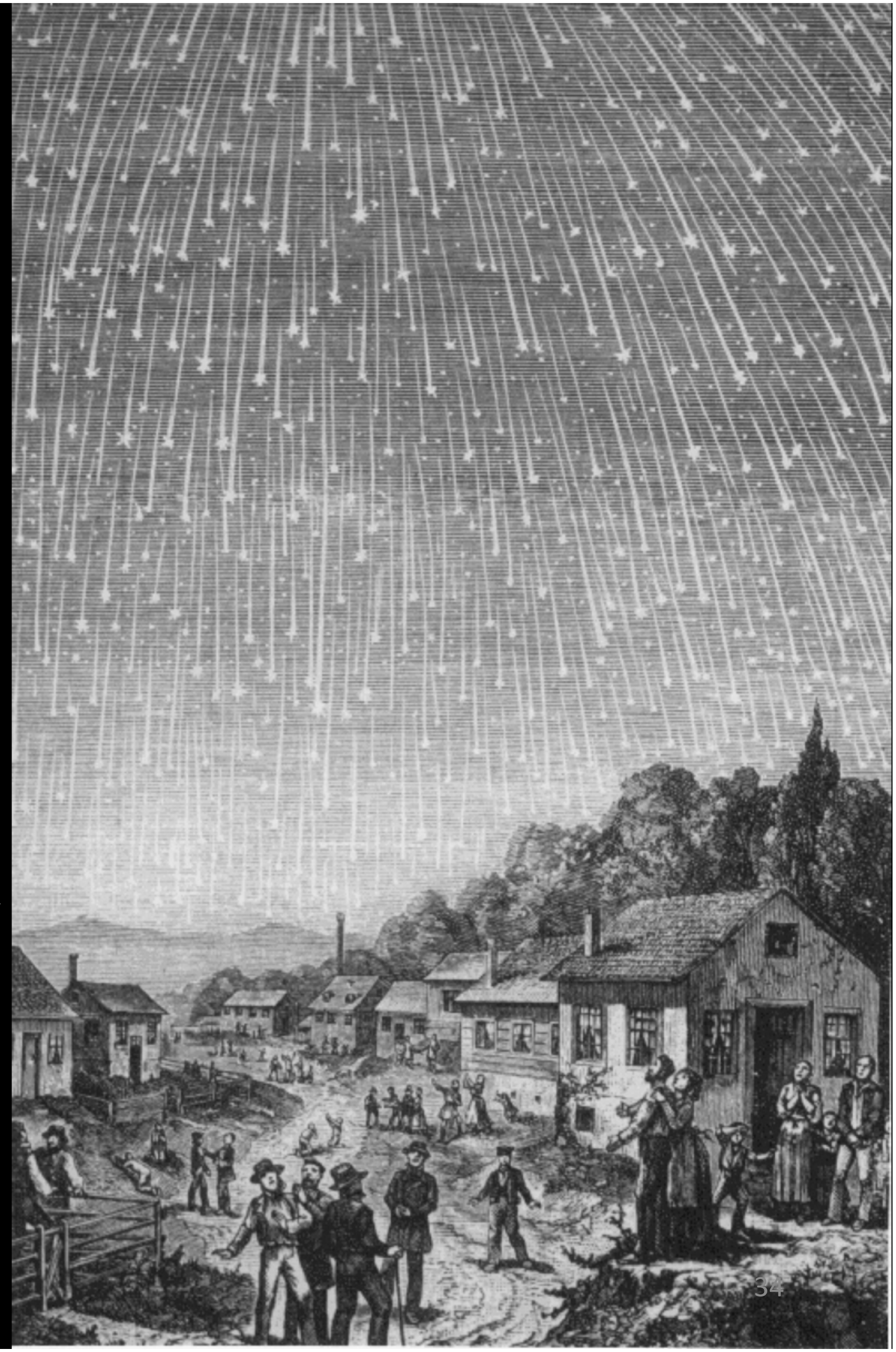
- Subsequent studies identified smaller amounts of Mg^+ on a daily basic from sporadic meteors (Crismani+17)
- Meteoric smoke particles may nucleate mesospheric clouds

Comparing Major Meteor Showers

1833 (Earth)
Leonid Meteor Shower
ZHR ~ thousands or tens of thousands meteors/hour

2014 (Mars)
Comet Siding Spring Meteor Shower
ZHR ~ thousands or tens of thousands meteors/hour

ZHR = Zenithal hourly rate

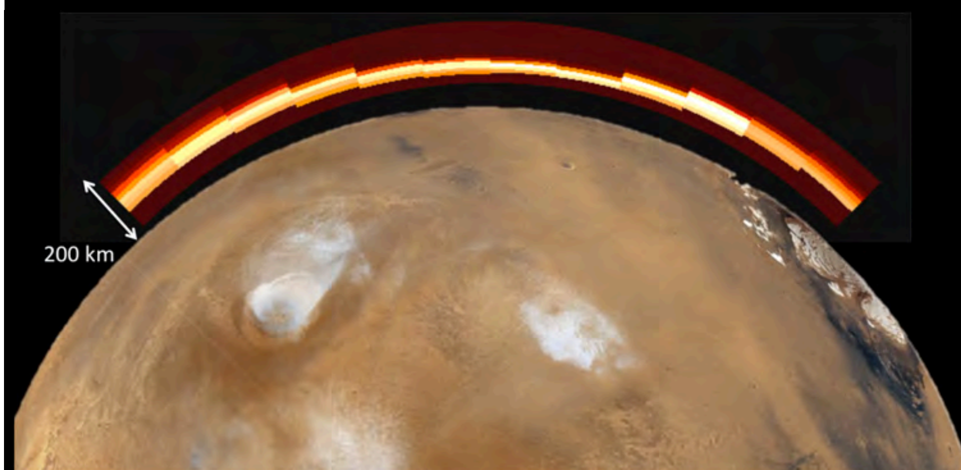


Meteoric Metals on Earth and Mars

Earth

Gemini South Sodium
Laser Guide Beacon

Mars



280 nm Mg^{+} emission from Mars' atmosphere following the Siding Spring Meteor Shower

- Comet Siding Spring caused the solar system's largest meteor shower observed in modern times
- Meteor ablation occurs in all planetary atmospheres and leaves high-altitude layers of metals and metal ions
- Exogenous elements change atmospheric chemistry, create ionospheric layers, and produce "meteoric smoke" which can seed clouds – and affect climate
- Only Earth's meteoric metals had been detected prior to MAVEN's detections by IUVS and NGIMS

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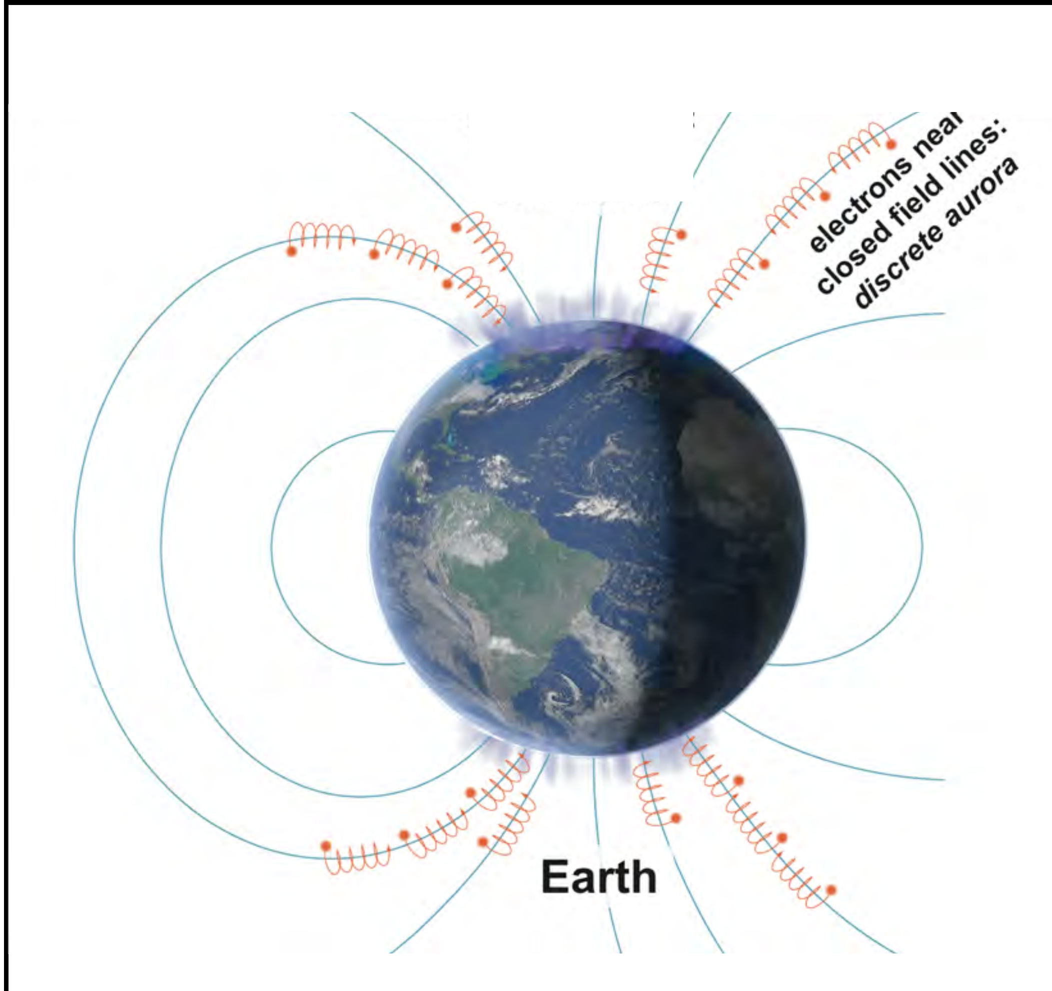
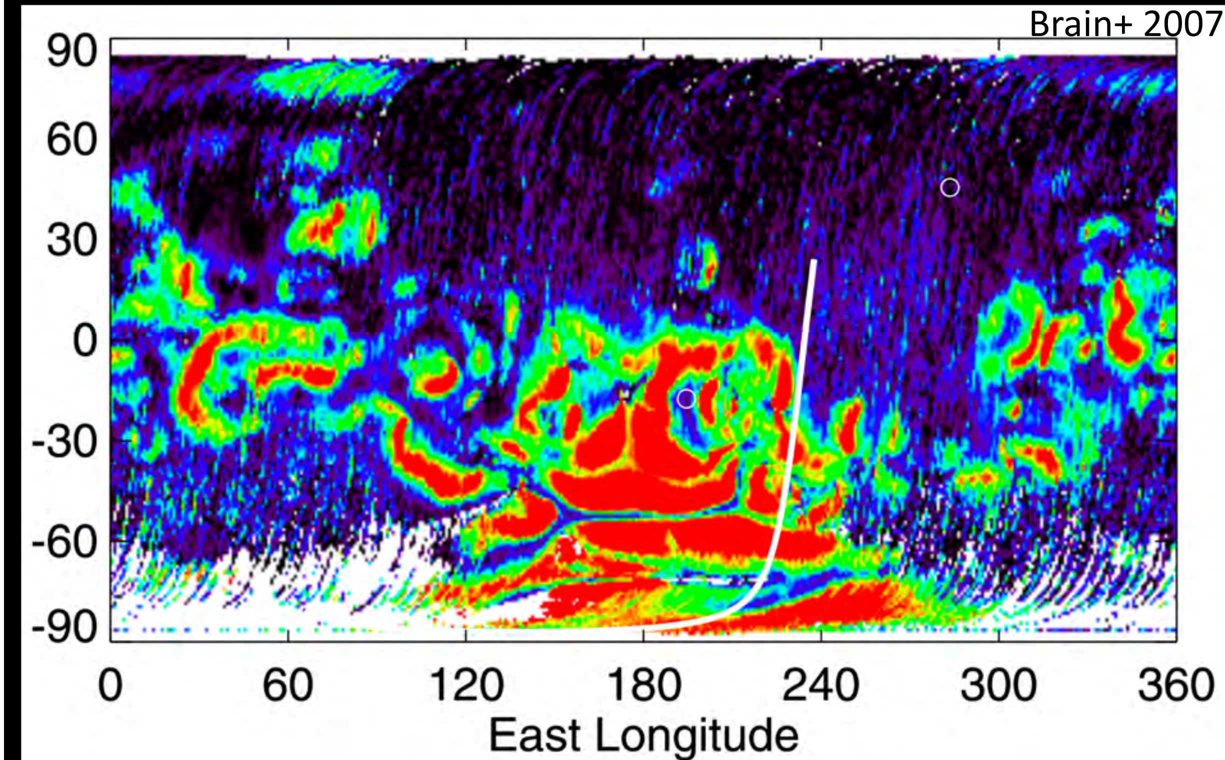
Auroral Processes at Earth



- Familiar terrestrial aurora occur near the edge of our dipole field, where interactions with the solar wind magnestic field can cause reconnection and energize particles within the magnetosphere

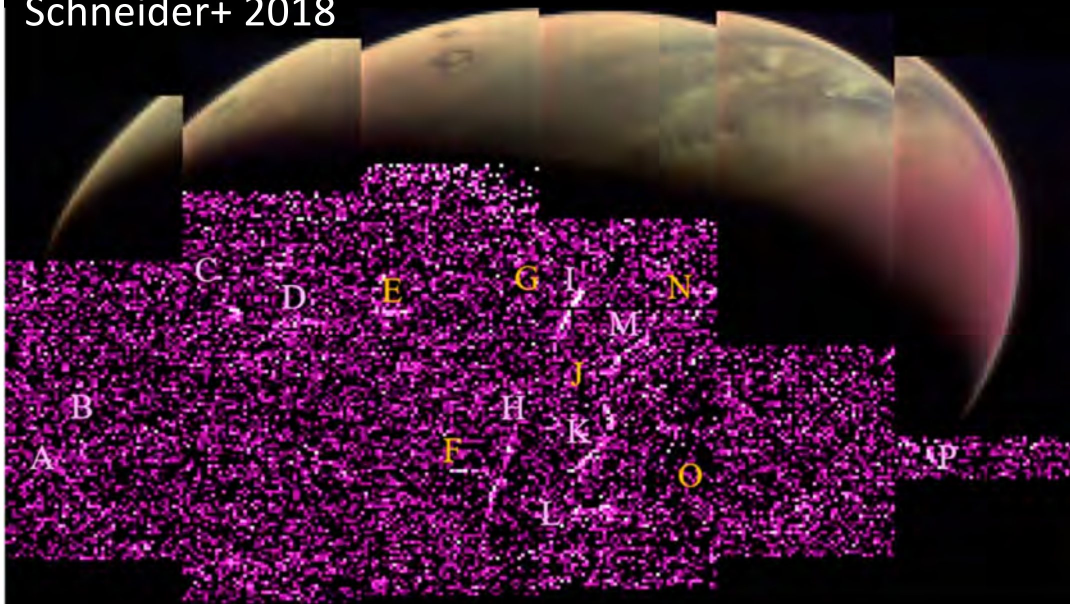
Patchy Magnetic Field, Patchy Aurora?



- MEX/SPICAM detected transient, small-scale *discrete aurora* "blobs" through UV spectroscopy (Bertaux+ 2005)
- Only near *remanent crustal fields* locked into ancient lava fields
- Confirmed scenario that aurora occur at the edges of a planet's magnetic field

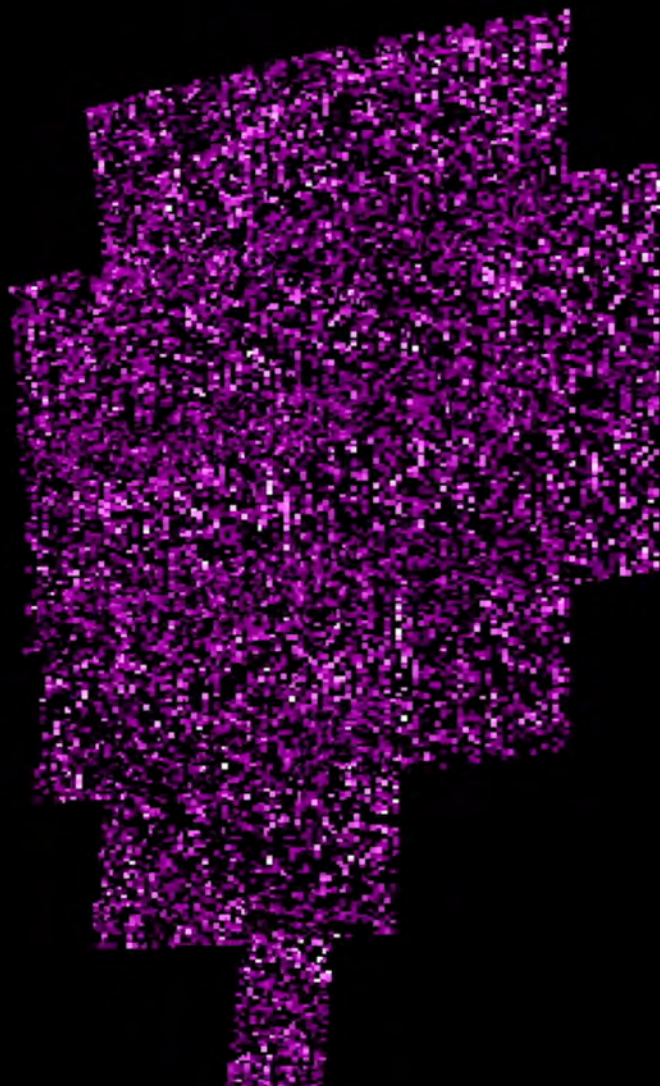
First Imaging of Discrete Aurora

Schneider+ 2018

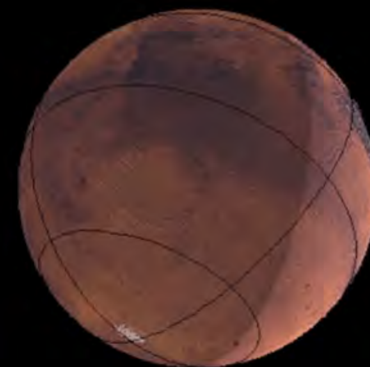


- Pixel-by-pixel examination shows excellent spectral match to auroral excitation

Mars during the 2017 extreme space weather event



Diffuse aurora on Mars are far more common and far brighter than discrete aurora

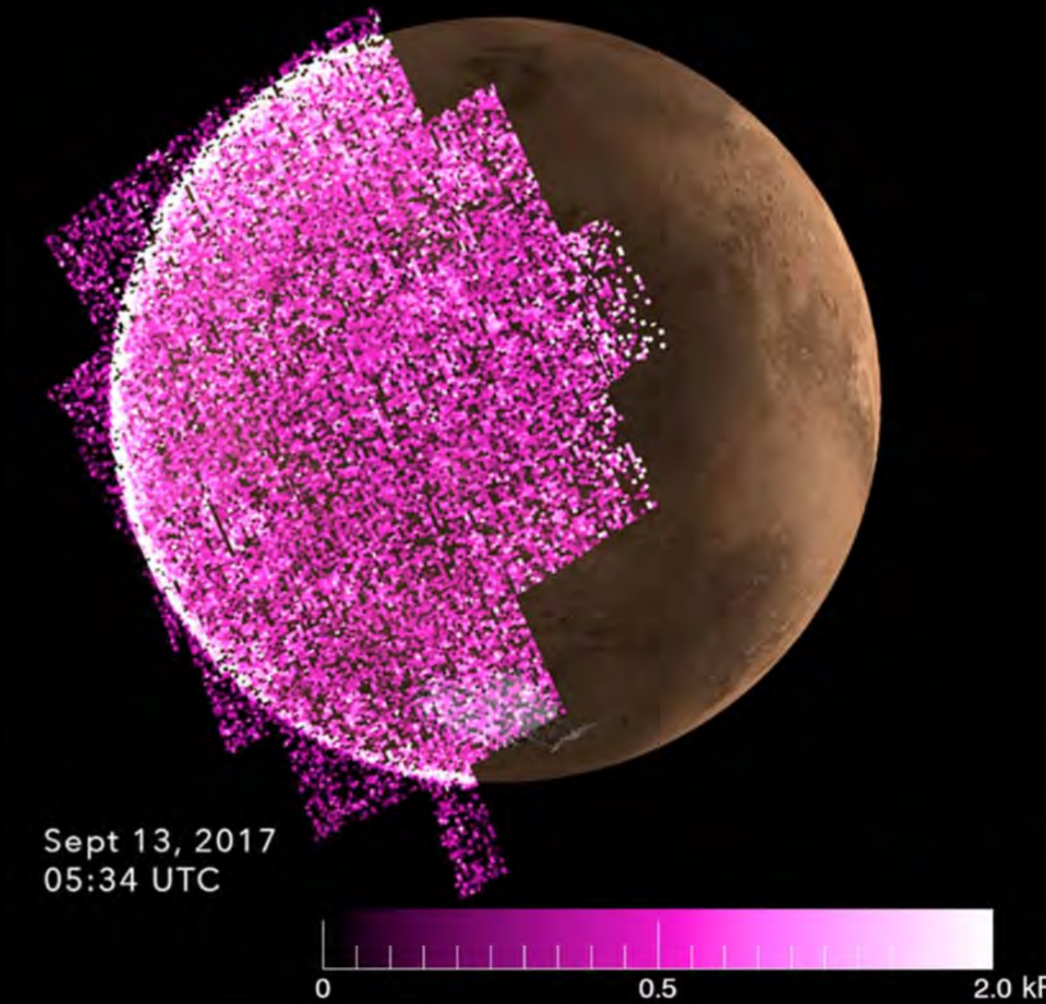


12 Sept 02:58

Aurora is global, visible around the limb and across the disk

Brightness indicates intensity of the CO Cameron bands

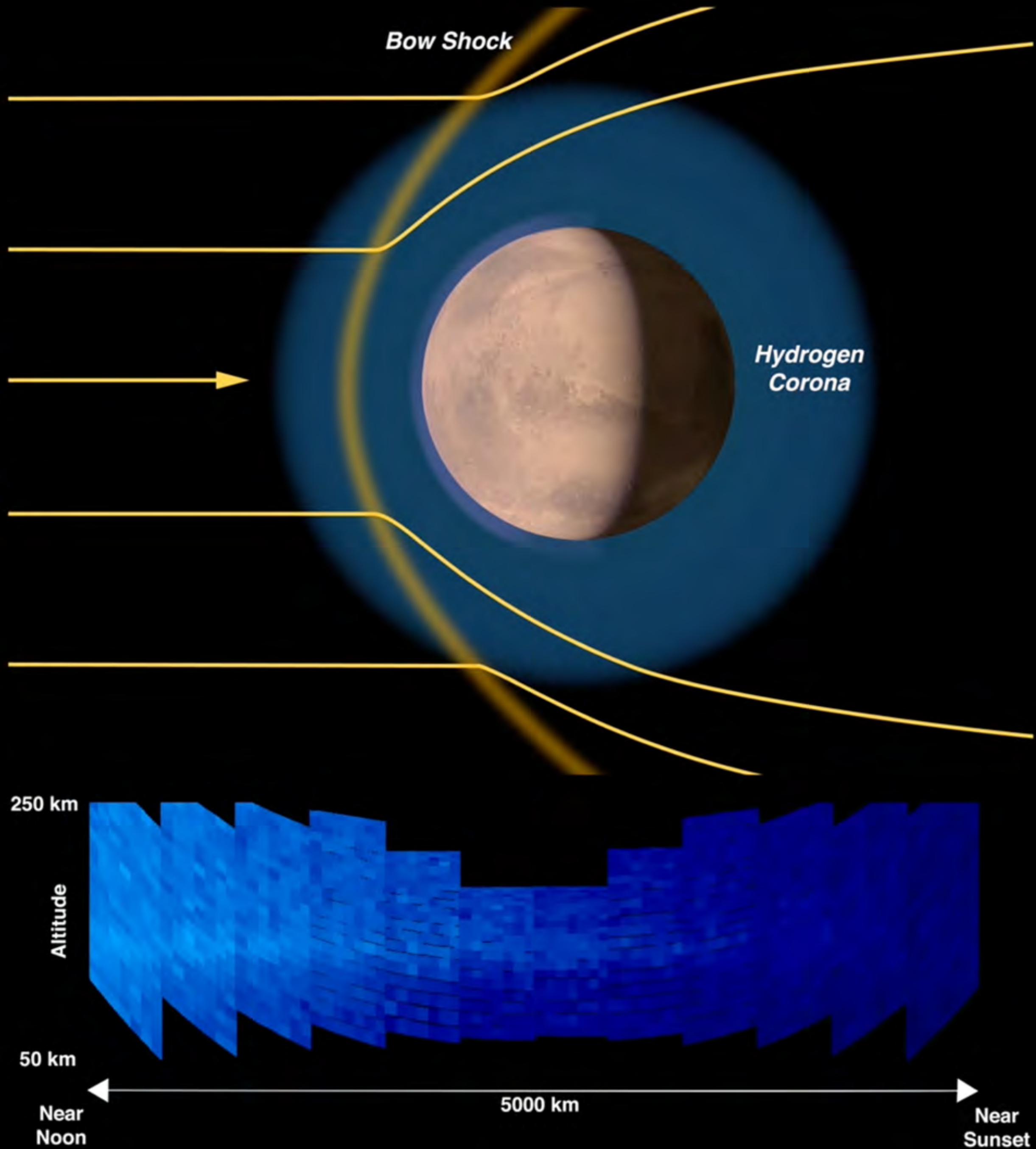
Diffuse Aurora: Global Effect of Intense Solar Activity



- Occurs globally & lasts for days; many MAVEN detections despite low solar activity
- Caused by penetration of solar energetic particles (~100 keV) down to ~70km altitude
- Reveals direct influence of the Sun on Mars' atmosphere; potential influence of energy deposition & chemistry not yet explored.
- Solar events likely produce visible aurora, but watching them could be hazardous

Schneider+ 2018

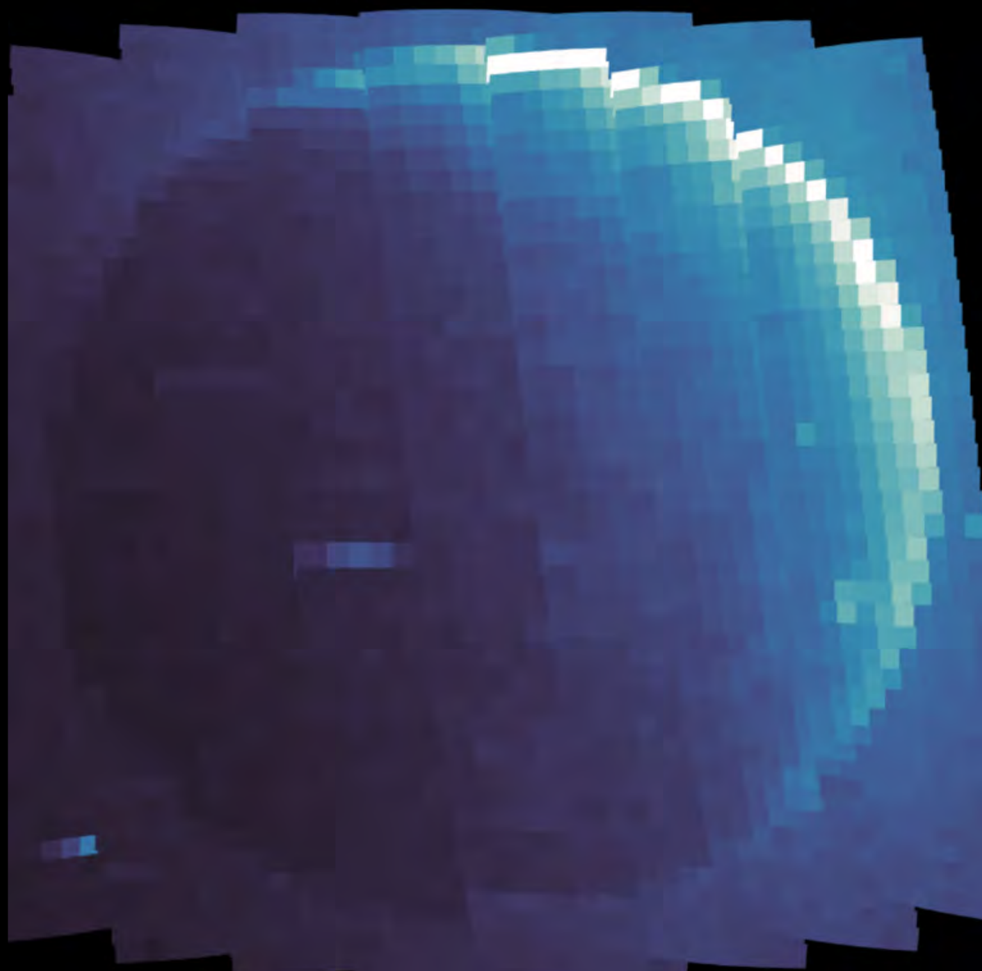
Proton Aurora: Mars' most common aurora



- Penetrating particles are neutralized by charge exchange, which allows them to pass through the bowshock (and emit!)
- Unlike all other auroral processes, in this case the penetrating particle emits light, not the background atmosphere
- Likely to occur on Venus, but has never been observed

Deighan+ 2018

Imaging Proton Aurora



Solar wind protons penetrating Mar's atmosphere emit Lyman Alpha photons around the limb, adding to Mars' coronal glow

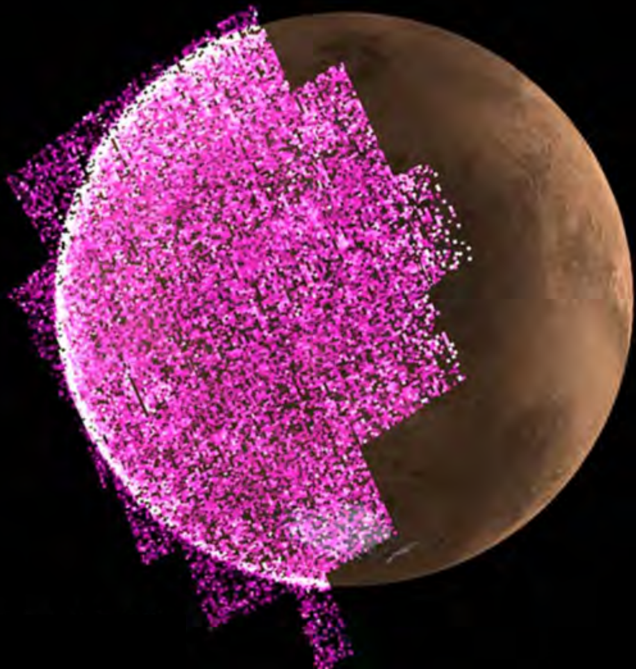
- Occurs frequently over entire dayside
- Occurs nearly continuously during southern summer when Mars' H corona is enhanced (Hughes+ 2019)

➢ Proton aurora can therefore serve as a proxy for H escape!

Three Types of Aurora on Mars

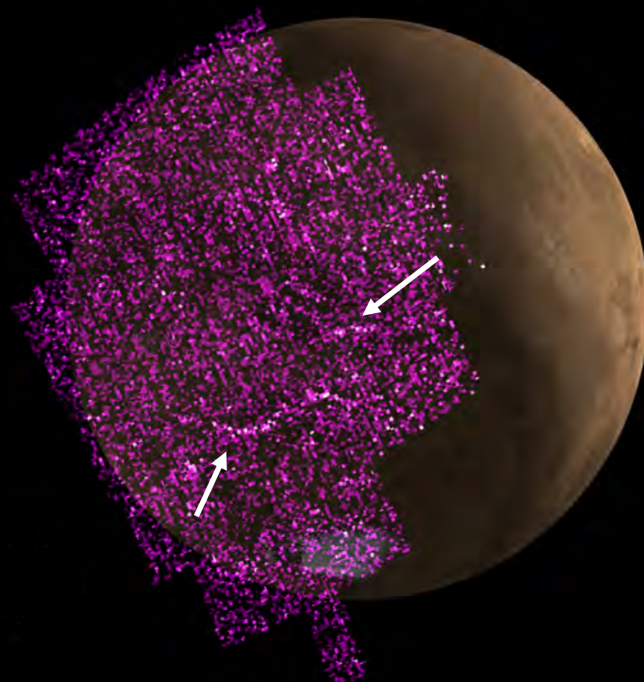
Observed by MAVEN’s Imaging UltraViolet Spectrograph

Diffuse Aurora



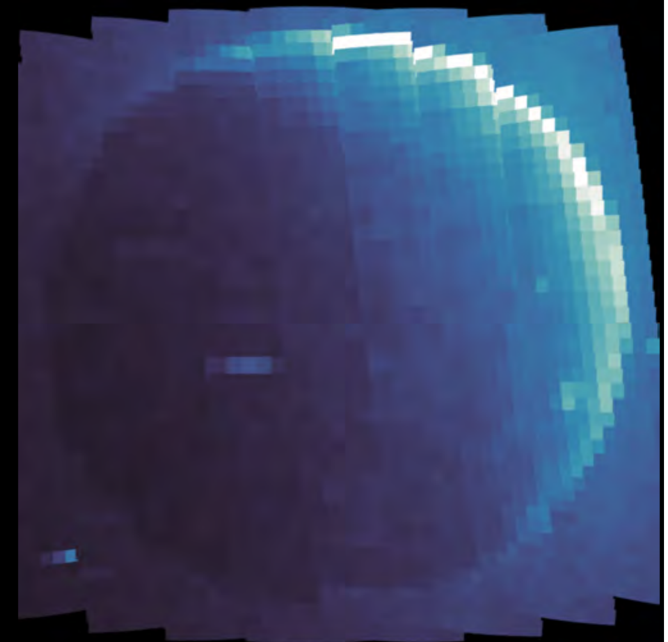
During strong space weather events, global aurora can engulf the planet, as in this image from September 2017

Discrete Aurora



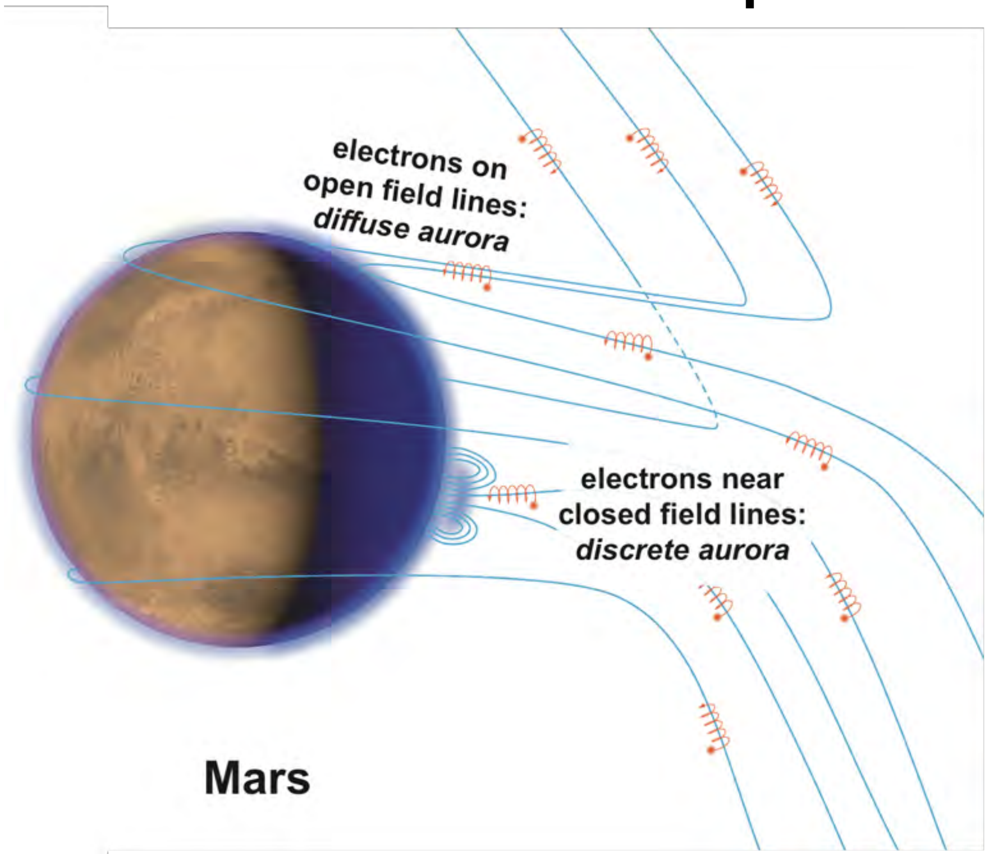
During solar storms, faint emissions (white arrows) cluster around remanent magnetic fields locked in regions of Mars’ crust

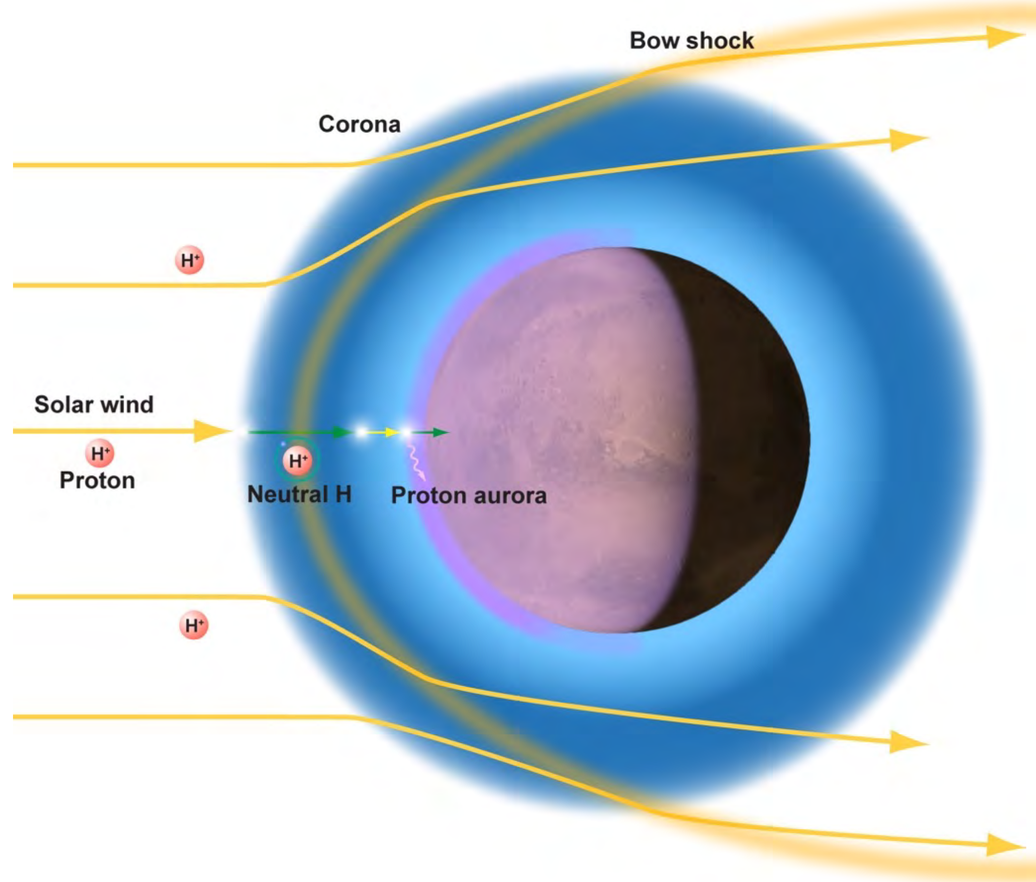
Proton Aurora



Solar wind protons penetrating Mar’s atmosphere emit Lyman Alpha photons around the limb, adding to Mars’ coronal glow

A More Complete View of Mars Aurora



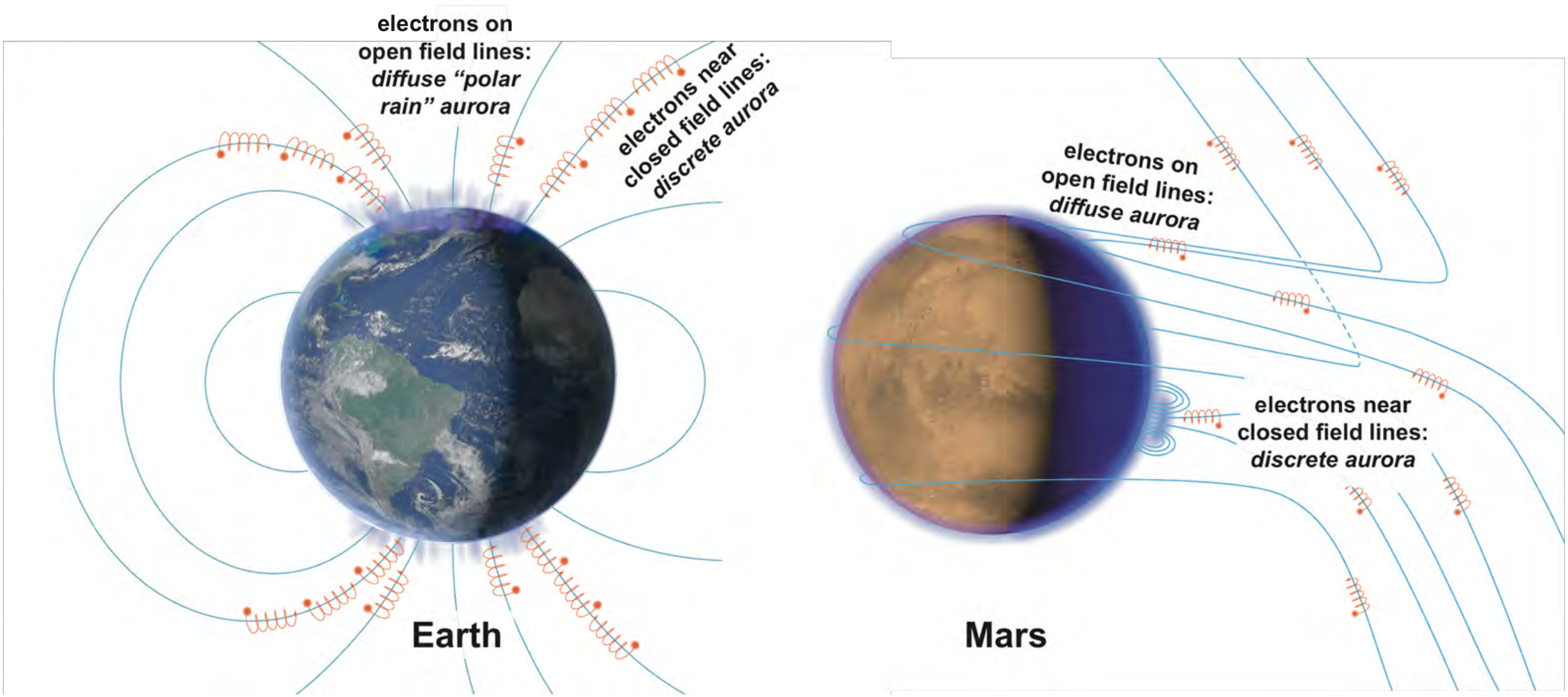


Diffuse and Discrete Aurora

Proton Aurora

- IUVS has discovered two forms of aurora (diffuse, proton) made possible by the *lack* of a global magnetic field
- Global magnetic fields should be considered both the cause and prevention of different types of aurora

Auroral Processes at Earth and Mars



- Magnetic fields in a planet's interior and crust exert strong control over where aurora occur
- Solar influence can determine auroral timing and strength

Aurora on Unmagnetized Planets

Implications for the Solar System and Exoplanets

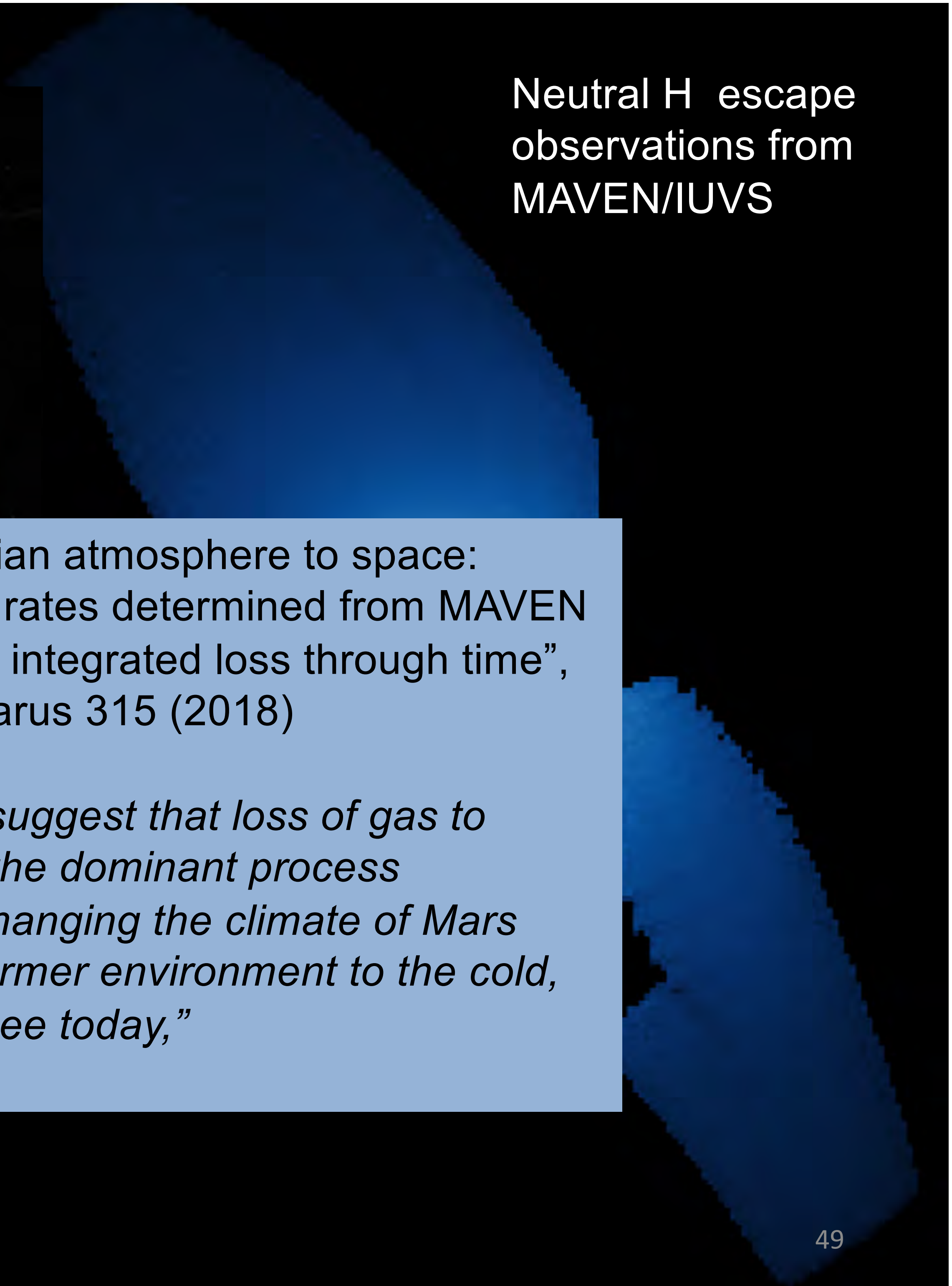
- Small exoplanets are abundant, so many may be Mars-like and lack magnetic fields
- Aurora on unmagnetized planets may be global with correspondingly greater effects
- Small stars with close-in exoplanets may experience substantial auroral activity

➢ Auroral activity should not be interpreted as evidence for a magnetic field

Surprises from MAVEN at Mars

- Mars, MAVEN & IUVS: a quick overview
- Selected highlights
  - Comet Siding Spring's encounter with Mars
  - Three types of aurora on Mars
  - A new paradigm for Mars water loss
- MAVEN: what's ahead?

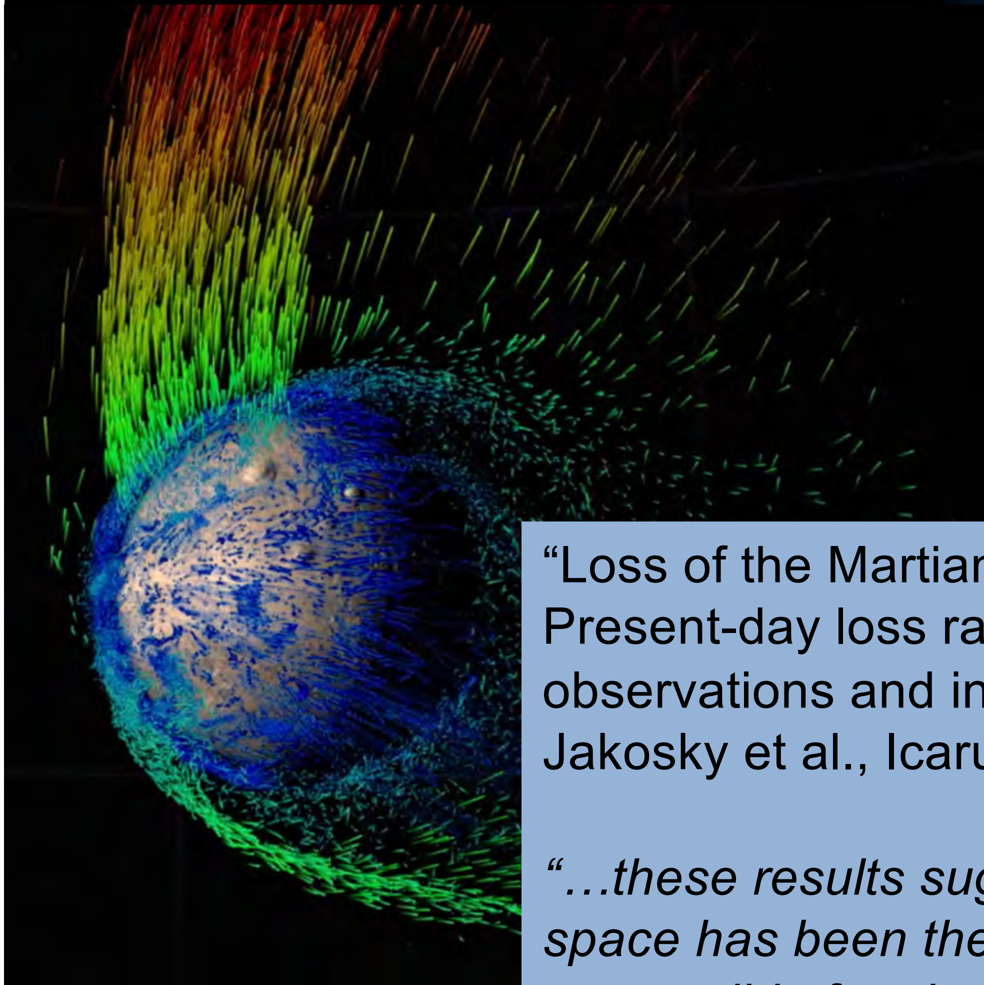
- Unifying themes
  - ➢ Interconnectedness of all branches of planetary science
  - ➢ Planetary responses to internal & external forcings



Neutral H escape observations from MAVEN/IUVS

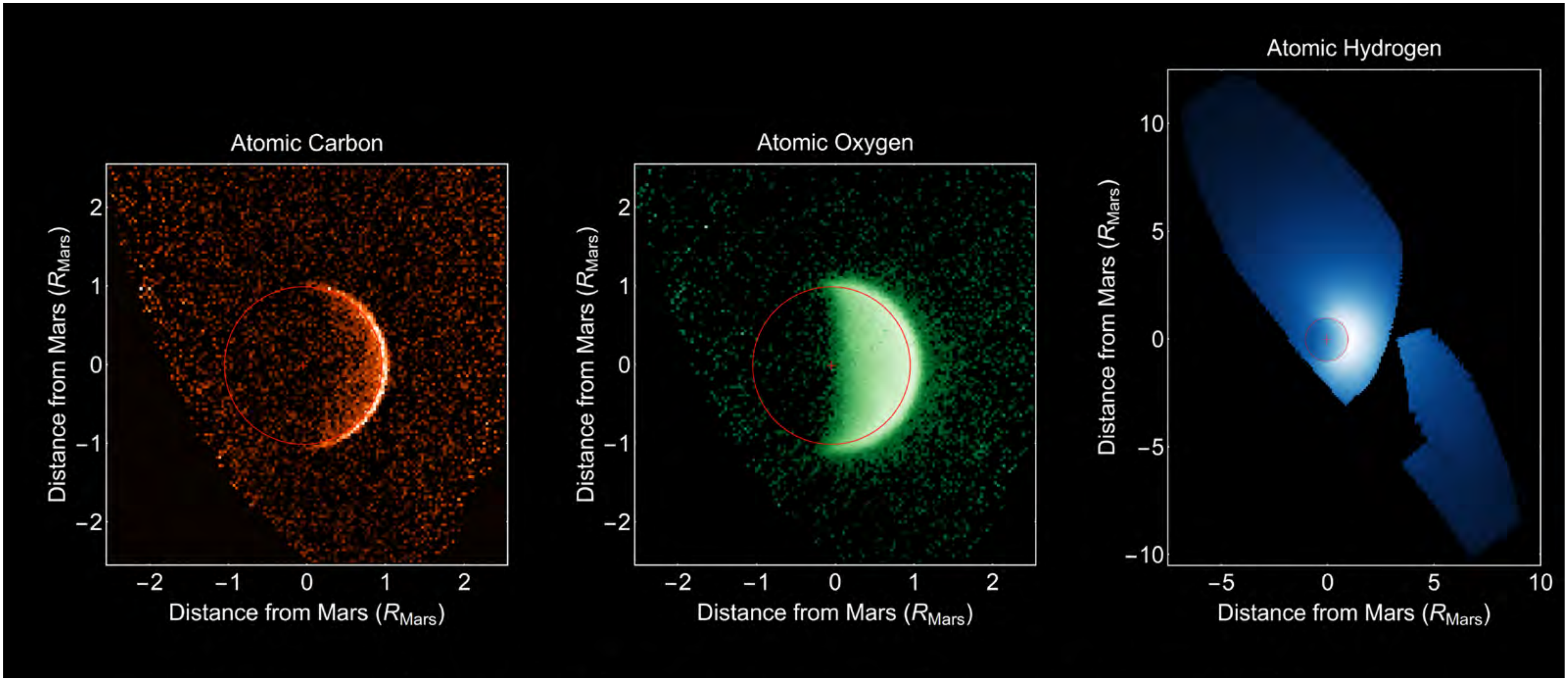
“Loss of the Martian atmosphere to space: Present-day loss rates determined from MAVEN observations and integrated loss through time”, Jakosky et al., Icarus 315 (2018)

“…these results suggest that loss of gas to space has been the dominant process responsible for changing the climate of Mars from an early, warmer environment to the cold, dry one that we see today,”



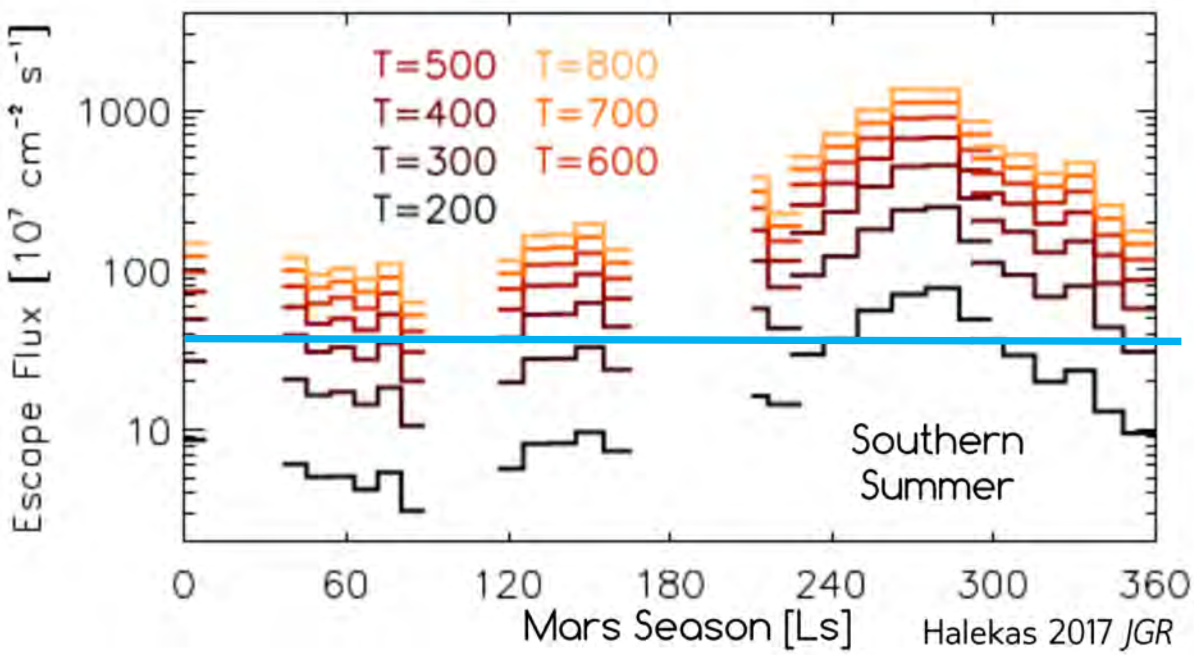
Ion escape model based on MAVEN’s fields-and-particle instruments

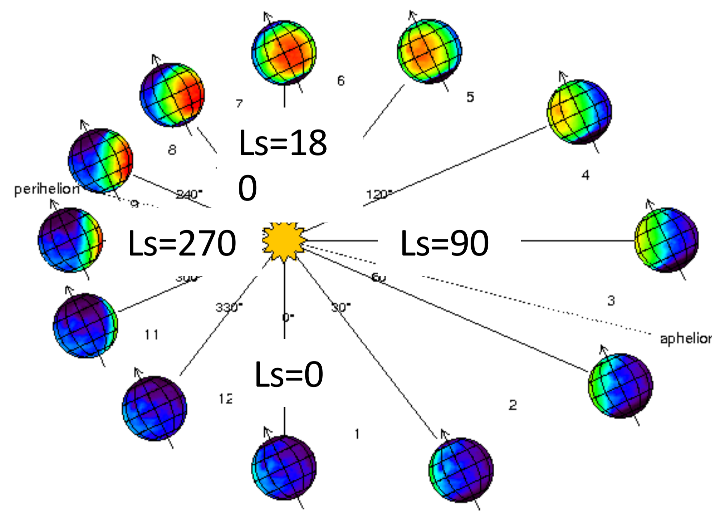
IUVS Observations of Atomic Components of H_2O and CO_2 on Their Way to Escaping



Work by Mike Chaffin & Justin Deighan

Ongoing MAVEN studies reveal the seasonal variability of Mars H Escape





See also Chaffin et al. (2014) GRL
Clarke et al. (2014) GRL,
Bhattacharyya et al (2015) GRL

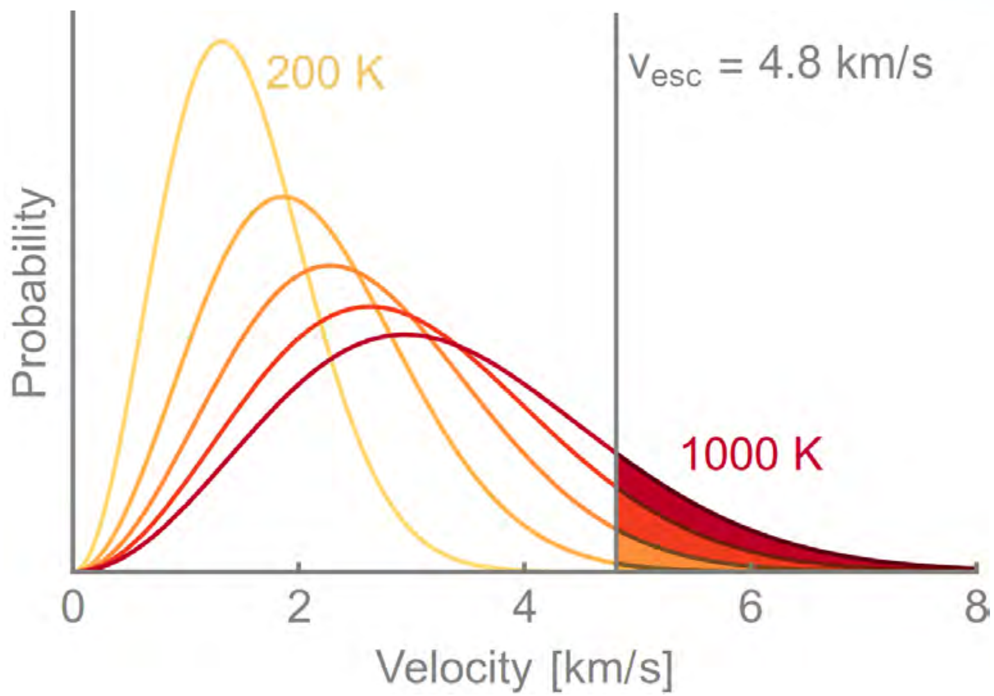
ARTICLES
PUBLISHED ONLINE: 30 JANUARY 2017 | DOI: 10.1038/NGEO2887
nature geoscience

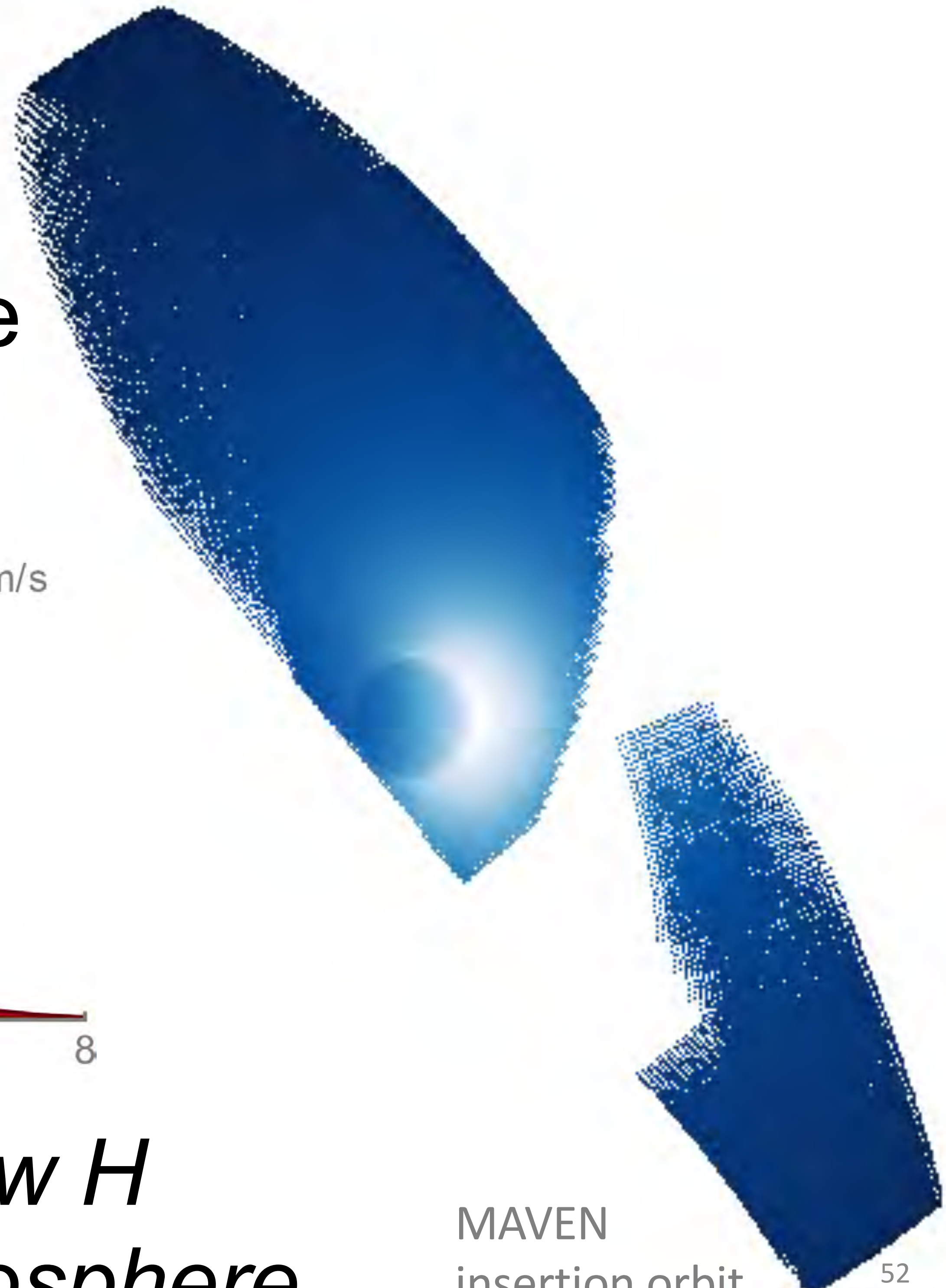
Elevated atmospheric escape of atomic hydrogen from Mars induced by high-altitude water

M. S. Chaffin*, J. Deighan, N. M. Schneider and A. I. F. Stewart

→Dust storms can break the cold trap, allowing H_2O to rise, undergo dissociation, and escape

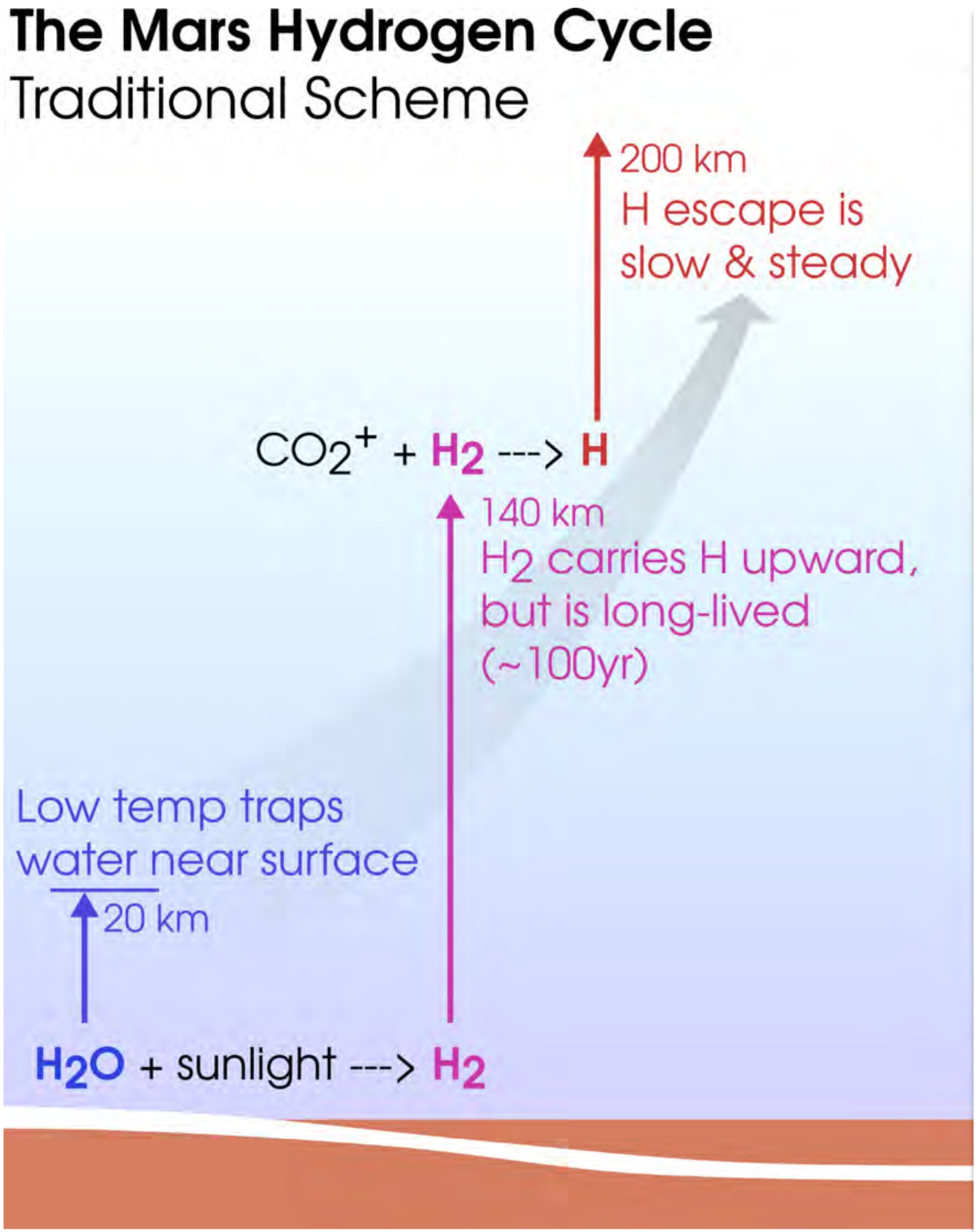
H is escaping from Mars today via thermal escape





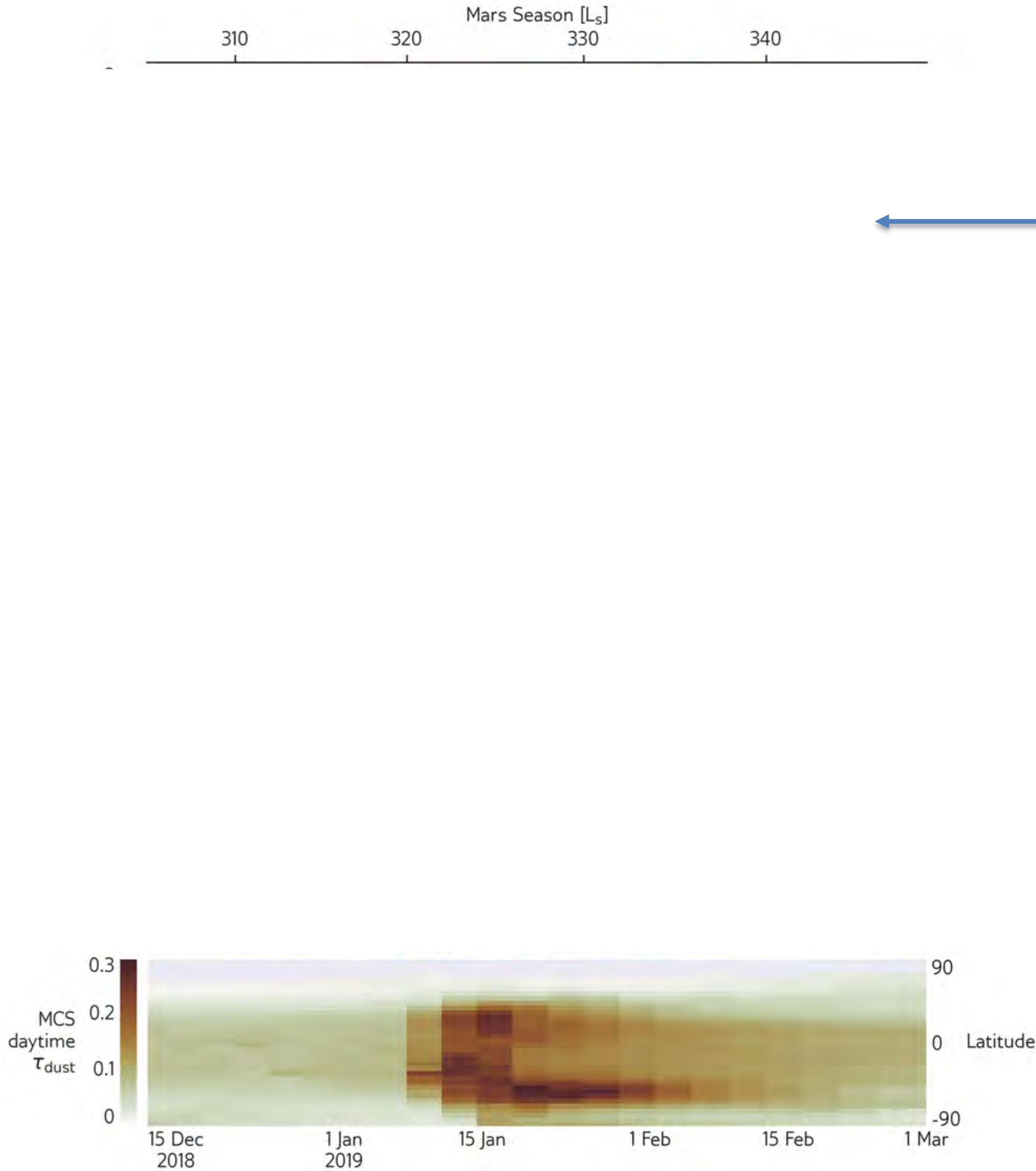
The question is how H rose above the exosphere

MAVEN insertion orbit



Chaffin+ 2020

Watching A Regional Dust Storm Drive Enhanced Escape: from the bottom to the top

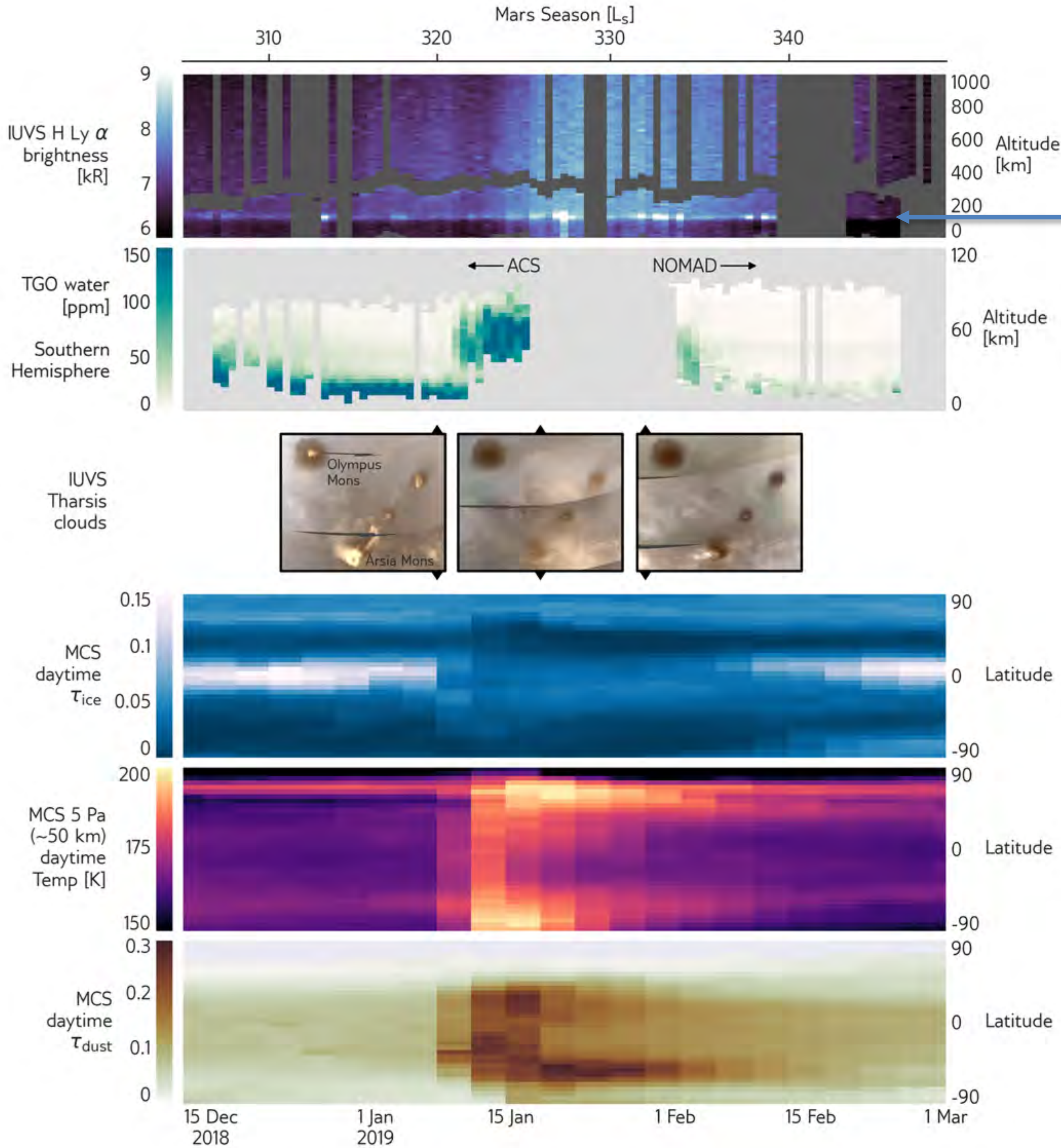


Proton Aurora
(white = more)

Low-atmosphere dust
(brown = more)

Chaffin+ 2020 (submitted)

Watching A Regional Dust Storm Drive Enhanced Escape: from the bottom to the top



Exospheric hydrogen

(blue = more)

Proton Aurora

(white = more)

Water Vapor

(green = more)

Topographic clouds

(white = more)

Low-atmosphere ice

(white = more)

Low-atmosphere Temp

(orange = warmer)

Low-atmosphere dust

(brown = more)

Chaffin+ 2020 (submitted)

A New Paradigm for Water Loss from Mars

- Multiple instruments on MAVEN and other spacecraft have identified southern hemisphere summer as a period of enhanced H escape, perhaps dominating the year's loss

- Water vapor is apparently breaking through the "cold trap" due to rapid mixing caused by extreme summer weather; observations & modeling show this can happen

- Over billions of years, water loss may have preferentially occurred during southern summer – not an equilibrium process

Surprises from MAVEN at Mars

- The Comet Siding Spring encounter
  - *Meteor ablation science comes to another planet*

- Three types of aurora on Mars
  - *"No magnetic field" causes widespread aurora*

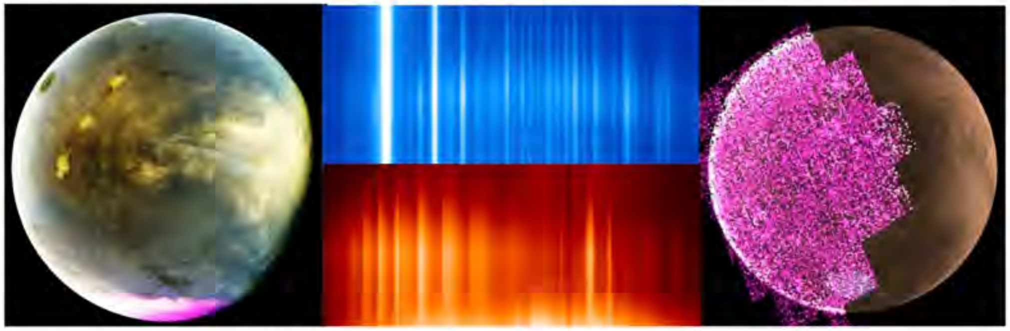
- A new paradigm for Mars water loss
  - *Seasonal loss mechanism must be tested*

- Interconnectedness of all branches of planetary science
- Planetary responses to internal & external forcings

What's Ahead for MAVEN?

- MAVEN continues its extended mission with better coverage of Mars seasons, solar activity, orbit geometry
- IUVS performing as well as at launch, operations aggressively enhanced over the mission
- MAVEN orbit recently changed, increasing its relay role as "router to the rovers" while still making observations
- Much more excellent science to come, perhaps into the 2030's!

*



MAVEN
Mars Atmosphere and Volatile Evolution Mission
CU/LASP • GSFC • UCB/SSL • LM • JPL

Postdoctoral Researcher with the MAVEN Imaging UltraViolet Spectrograph Team

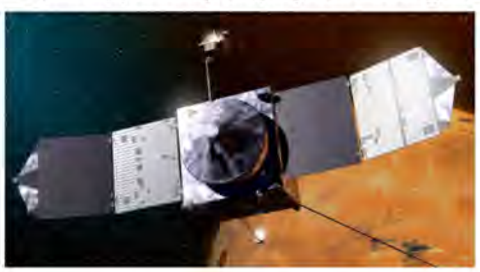
Summary. The Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder is seeking a talented scientist to work with the Imaging Ultraviolet Spectrograph (IUVS) team on the MAVEN mission. The IUVS team has made important discoveries in the areas of Mars aeronomy, atmospheric escape and evolution, aurora, nightglow, photochemistry, composition, dynamics and cloud formation, and more discoveries are anticipated. The team is led by Nick Schneider.

Key Responsibilities: Observational studies of the Mars atmosphere through ultraviolet spectroscopy and imaging. Scientific analysis of data obtained, publication of results in appropriate scientific journals and presentation at conferences. Support for mission/instrument operations and observation planning. Operation and enhancement of automated data processing pipelines including retrievals of atmospheric properties. Mentoring of graduate and undergraduate student researchers.

Position Requirements: Ph.D in Planetary Science, Astronomy, Atmospheric Science, Physics or a related field. Coding proficiency in python, IDL or other scientific computing languages.

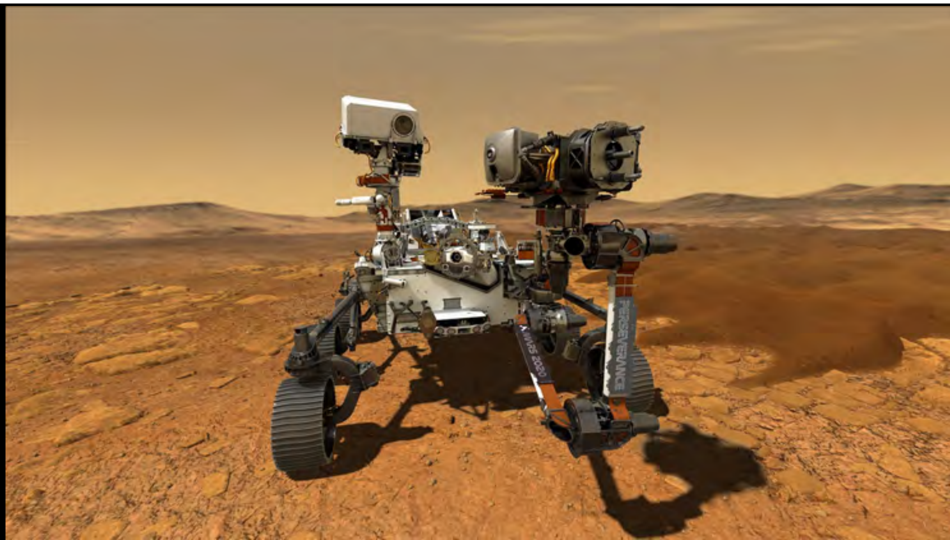
Desired Qualifications: Skill with data analysis, image processing and statistics. Familiarity with Mars atmospheric science, including *one or more of the following*: atmospheric structure, dayglow, nightglow, aurora, photochemistry, ultraviolet spectroscopy, atmospheric evolution, climate, waves and tides, familiarity with General Circulation Models and numerical simulation.

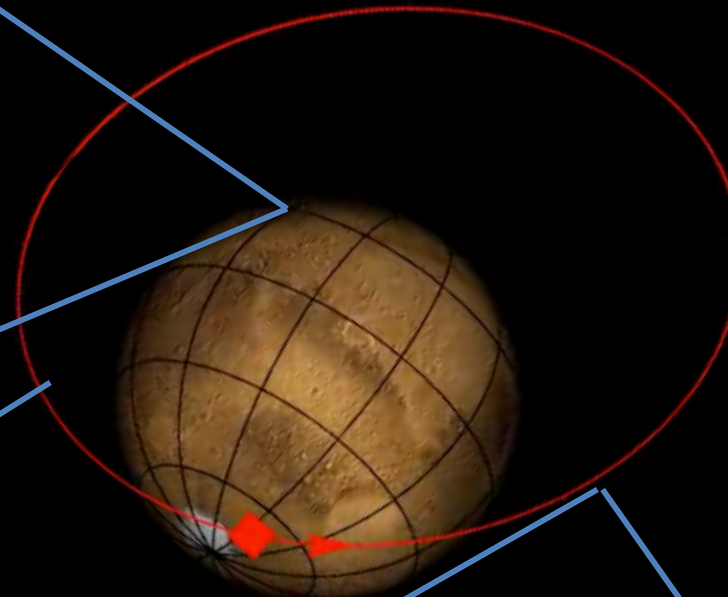
Please see https://jobs.colorado.edu/jobs/jobDetail?jobId=21086 for additional information about the University, LASP, benefits, etc. The University of Colorado Boulder is committed to building a culturally diverse community of faculty, staff, and students dedicated to contributing to an inclusive campus environment. We are an Equal Opportunity employer, including veterans and individuals with disabilities.

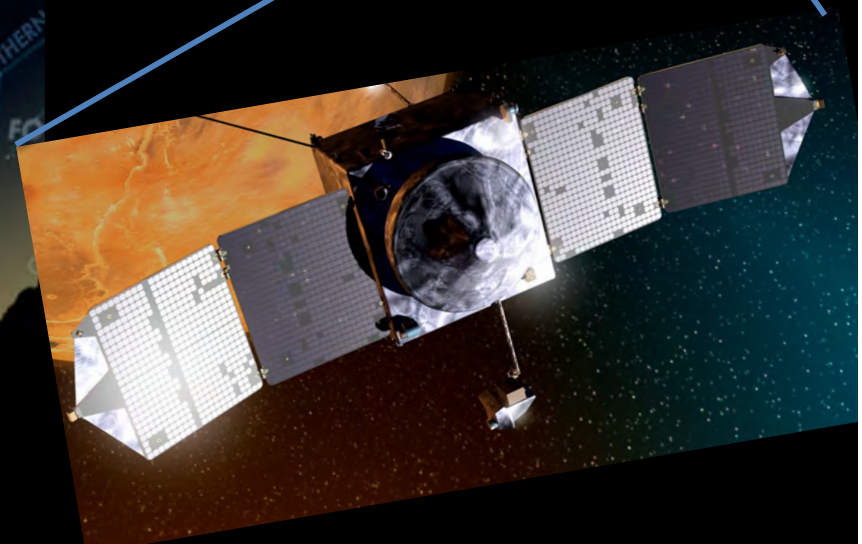


IUVS is looking for a new postdoc!

Please contact me directly







~10pm 23 September

Thanks for your invitation and interest!

Nick.Schneider@lasp.Colorado.edu